Estimating Surface Reflectance Properties of a Complex Scene under Captured Natural Illumination

Paul Debevec Chris Tchou Andrew Gardner Tim Hawkins
Charis Poullis Jessi Stumpfel Andrew Jones Nathaniel Yun
Per Einarsson Therese Lundgren Marcos Fajardo Philippe Martinez†
University of Southern California Institute for Creative Technologies Graphics Laboratory
Ecole Normale Superiure†

Fig. 1: (a) One of eight input photographs (b) Estimated reflectance properties (c) Synthetic rendering with novel lighting

ABSTRACT

We present a process for estimating spatially-varying surface reflectance of a complex scene observed under natural illumination conditions. The process uses a laser-scanned model of the scene's geometry, a set of digital images viewing the scene's surfaces under a variety of natural illumination conditions, and a set of corresponding measurements of the scene's incident illumination in each photograph. The process then employs an iterative inverse global illumination technique to compute surface colors for the scene which, when rendered under the recorded illumination conditions, best reproduce the scene's appearance in the photographs. In our process we measure BRDFs of representative surfaces in the scene to better model the non-Lambertian surface reflectance. Our process uses a novel lighting measurement apparatus to record the full dynamic range of both sunlit and cloudy natural illumination conditions. We employ Monte-Carlo global illumination, multiresolution geometry, and a texture atlas system to perform inverse global illumination on the scene. The result is a lighting-independent model of the scene that can be re-illuminated under any form of lighting. We demonstrate the process on a real-world archaeological site, showing that the technique can produce novel illumination renderings consistent with real photographs as well as reflectance properties that are consistent with ground-truth reflectance measurements.

1 Introduction

Digitizing objects and environments from the real world has become an important part of creating realistic computer graphics. Capturing geometric models has become a common process through the use of structured lighting, laser triangulation, and laser time-of-flight measurements. Recent projects such as [Levoy et al. 2000; Rushmeier et al. 1998; Ikeuchi 2001] have shown that accurate and detailed geometric models can be acquired of real-world objects using these techniques.

To produce renderings of an object under changing lighting as well as viewpoint, it is necessary to digitize not only the object's geometry but also its reflectance properties: how each point of the object reflects light. Digitizing reflectance properties has proven to be a complex problem, since these properties can vary across the surface of an object, and since the reflectance properties of even a single surface point can be complicated to express and measure. Some of the best results that have been obtained [Rushmeier et al. 1998; Marschner 1998; Lensch et al. 2003] capture digital photographs of objects from a variety of viewing and illumination directions, and from these measurements estimate reflectance model parameters for each surface point.

Digitizing the reflectance properties of outdoor scenes can be more complicated than for objects since it is more difficult to control the illumination and viewpoints of the surfaces. Surfaces are most easily photographed from ground level rather than from a full range of angles. During the daytime the illumination conditions in an environment change continuously. Finally, outdoor scenes generally exhibit significant mutual illumination between their surfaces, which must be accounted for in the reflectance estimation process. Two recent pieces of work have made important inroads into this problem. [Yu and Malik 1998] estimated spatially varying reflectance properties of an outdoor building based on fitting observations of the incident illumination to a sky model, and [Yu et al. 1999] estimated reflectance properties of a room interior based on known light source positions and using a finite element radiosity technique to take surface interreflections into account.

In this paper, we describe a process that synthesizes previous results for digitizing geometry and reflectance and extends them to the context of digitizing a complex real-world scene observed under arbitrary natural illumination. The data we acquire includes a geometric model of the scene obtained through laser scanning, a set of photographs of the scene under various natural illumination conditions, a corresponding set of measurements of the incident illumination for each photograph, and finally, a small set of BRDF measurements of representative surfaces within the scene. To estimate the scene's reflectance properties, we use a global illumination algorithm to render the model from each of the photographed viewpoints as illuminated by the corresponding incident illumination measurements. We compare these renderings to the photographs, and then iteratively update the surface reflectance properties to best correspond to the scene's appearance in the photographs. Full BRDFs for the scene's surfaces are inferred from the measured BRDF samples. The result is a set of estimated reflectance prop-

erties for each point in the scene that most closely generates the scene's appearance under all input illumination conditions.

While the process we describe leverages existing techniques, our work includes several novel contributions. These include our incident illumination measurement process, which can measure the full dynamic range of both sunlit and cloudy natural illumination conditions, a hand-held BRDF measurement process suitable for use in the field, and an iterative multiresolution inverse global illumination process capable of estimating surface reflectance properties from multiple images for scenes with complex geometry seen under complex incident illumination.

The scene we digitize is the Parthenon in Athens, Greece, done in collaboration with the ongoing Acropolis Restoration project. Scaffolding and equipment around the structure prevented the application of the process to the middle section of the temple, but we were able to derive models and reflectance parameters for both the East and West facades. We validated the accuracy of our results by comparing our reflectance measurements to ground truth measurements of specific surfaces around the site, and we generate renderings of the model under novel lighting that are consistent with real photographs of the site. At the end of the paper we discuss avenues for future work to increase the generality of these techniques.

2 Background and Related Work

The process we present leverages previous results in 3D scanning, reflectance modeling, lighting recovery, and reflectometry of objects and environments. Techniques for building 3D models from multiple range scans generally involve first aligning the scans to each other [Besl and McKay 1992; Chen and Medioni 1992], and then combining the scans into a consistent geometric model by either "zippering" the overlapping meshes [Turk and Levoy 1994] or using volumetric merging [Curless and Levoy 1996] to create a new geometric mesh that optimizes its proximity to all of the available scans.

In its simplest form, a point's reflectance properties can be expressed in terms of its Lambertian surface color - usually an RGB triplet expressing the point's red, green, and blue reflectance properties. More complex reflectance models can include parametric models of specular and retroflective components; some commonly used models are [Larson 1992; Oren and Nayar 1994; Lafortune et al. 1997]. More generally, a point's reflectance can be characterized in terms of its Bi-directional Reflectance Distribution Function (BRDF) [Nicodemus et al. 1977], which is a 4D function that characterizes for each incident illumination direction the complete distribution of reflected illumination. [Marschner et al. 1999] proposed an efficient method for measuring a material's BRDFs if a convex homogeneous sample is available. Recent work has proposed models which also consider scattering of illumination within translucent materials [Jensen et al. 2001].

To estimate a scene's reflectance properties, we use an incident illumination measurement process. [Marschner and Greenberg 1997] recovered low-resolution incident illumination conditions by observing an object with known geometry and reflectance properties. [Sato et al. 1999] estimated incident illumination conditions by observing the shadows cast from objects with known geometry. [Debevec 1998] acquired high resolution lighting environments by taking high dynamic range images [Debevec and Malik 1997] of a mirrored sphere, but did not recover natural illumination environments where the sun was directly visible. We combine ideas from Debevec:1998:RSO, and [Marschner and Greenberg 1997] to record high-resolution incident illumination conditions in cloudy, partly cloudy, and sunlit environments.

Considerable recent work has presented techniques to measure spatially-varying reflectance properties of objects. [Marschner 1998] used photographs of a 3D scanned object taken under point-light source illumination to estimate its spatially varying diffuse albedo. This work used a texture atlas system to store the surface colors of arbitrarily complex geometry, which we also perform in our work. The work assumed that the object was Lambertian, and only considered local reflections of the illumination. [Sato et al. 1997] used a similar sort of dataset to compute a spatially-varying diffuse component and a sparsely sampled specular component of an object. [Rushmeier et al. 1998] used a photometric stereo technique (e.g. [Ikeuchi and Horn 1979; Nayar et al. 1994]) to estimate spatially varying Lambertian color as well as improved surface normals for the geometry. [Rocchini et al. 2002] used this technique to compute diffuse texture maps for 3D scanned objects from multiple images. [Debevec et al. 2000] used a dense set of illumination directions to estimate spatially-varying diffuse and specular parameters and surface normals. [Lensch et al. 2003] presents an advanced technique for recovering spatially-varying BRDFs of real-world objects, performing principal component analysis of relatively sparse lighting and viewing directions to cluster the object's surfaces into patches of similar reflectance. In this way, many reflectance observations of the object as a whole are used to estimate spatially-varying BRDF models for surfaces seen from limited viewing and lighting directions. Our reflectance modeling technique is less general, but adapts ideas from this work to estimate spatially-varying non-Lambertian reflectance properties of outdoor scenes observed under natural illumination conditions, and we also account for mutual illumination.

Capturing the reflectance properties of surfaces in large-scale environments can be more complex, since it can be harder to control the lighting conditions on the surfaces and the viewpoints from which they are photographed. [Yu and Malik 1998] solved for the reflectance properties of a polygonal model of an outdoor scene modeled with photogrammetry. The technique used photographs taken under clear sky conditions, fitting a small number of radiance measurements to a parameterized sky model. The process estimated spatially varying diffuse and piecewise constant specular parameters, but did not consider retroreflective components. The process derived two *pseudo-BRDFs* for each surface, one according to its reflectance of light from the sun and one according to its reflectance of light from the sky and environment. This allowed more general spectral modeling but required every surface to be observed under direct sunlight in at least one photograph, which we do not require. Using room interiors, [Yu et al. 1999; Loscos et al. 1999; Boivin and Gagalowicz 2002] estimate spatially varying diffuse and piecewise constant specular parameters using inverse global illumination. The techniques used knowledge of the position and intensity of the scene's light sources, using global illumination to account for the mutual illumination between the scene's surfaces. Our work combines and extends aspects of each of these techniques: we use pictures of our scene under natural illumination conditions, but we image the illumination directly in order to use photographs taken in sunny, partly sunny, or cloudy conditions. We infer non-Lambertian reflectance from sampled surface BRDFs. We do not consider full-spectral reflectance, but have found RGB imaging to be sufficiently accurate for the natural illumination and reflectance properties recorded in this work. We provide comparisons to ground truth reflectance for several surfaces within the scene. Finally, we use a more general Monte-Carlo global illumination algorithm to perform our inverse rendering, and we employ a multiresolution geometry technique to efficiently process a complex laser-scanned model.

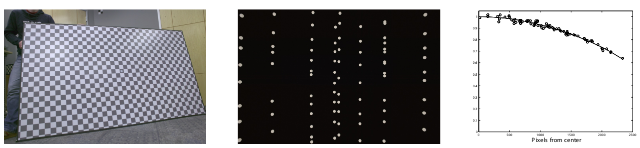
3 Data Acquisiton and Calibration

3.1 Camera Calibration

In this work we used a Canon EOS D30 and a Canon EOS 1Ds digital camera, which were calibrated geometrically and radiomet-

rically. For geometric calibration, we used the Camera Calibration Toolbox for Matlab [Bouguet 2002] which uses techniques from [Zhang 2000]. Since changing the focus of a lens usually changes its focal length, we calibrated our lenses at chosen fixed focal lengths. The main lens used for photographing the environment was a 24mm lens focussed at infinity. Since a small calibration object held near this lens would be out of focus, we built a larger calibration object 1.2m $\times$ 2.1m from an aluminum honeycomb panel with a 5cm square checkerboard pattern applied (Fig. 2(a)). Though nearly all images were acquired at f/8 aperture, we verified that the camera intrinsic parameters varied insignificantly (less than 0.05%) with changes of f/stop from f/2.8 to f/22.

In this work we wished to obtain radiometrically linear pixel values that would be consistent for images taken with different cameras, lenses, shutter speeds, and f/stops. We verified that the ”RAW” 12-bit data from the cameras was linear using three methods: we photographed a gray scale calibration chart, we used the radiometric self-calibration technique of [Debevec and Malik 1997], and we verified that pixel values were proportional to exposure times for a static scene. From this we found that the RAW pixel values exhibited linear response to within 0.1% for values up to 3000 out of 4095, after which saturation appeared to reduce pixel sensitivity. We ignored values outside of this linear range, and we used multiple exposures to increase the effective dynamic range of the camera when necessary.



(a) (b) (c)

Figure 2: **(a)** 1.2m$\times$2.1m geometric calibration object **(b)** Lens falloff measurements for 24mm lens at f/8 **(c)** Lens falloff curve for (b)

Most lenses exhibit a radial intensity falloff, producing dimmer pixel values at the periphery of the image. We mounted each camera on a Kaidan nodal rotation head and photographed a diffuse disk light source at an array of positions for each lens at each f/stop used for data capture (Fig. 2(b)). From these intensities recorded at different image points, we fit a radially symmetric 6th-order even polynomial to model the falloff curve and produce a flat-field response function, normalized to unit response at the image center.

The digital cameras used each had minor variations in sensitivity and color response. We calibrated these variations by photographing a MacBeth color checker chart under natural illumination with each camera, lens, and f/stop combination, and solved for the best 3×3 color matrix to convert each image into the same color space. Finally we used a utility for converting RAW images to floating-point images using the EXIF metadata for camera model, lens, ISO, f/stop, and shutter speed to apply the appropriate radiometric scaling factors and matrices. These images were organized in a PostGreSQL database for convenient access.

3.2 BRDF Measurement and Modeling

In this work we measure BRDFs of a set of representative surface samples, which we use to form the most plausible BRDFs for the rest of the scene. Our relatively simple technique is motivated by the principal component analyses of reflectance properties used in [Lensch et al. 2003] and [Matusik et al. 2003], except that we choose our basis BRDFs manually. Choosing the principal BRDFs in this way meant that BRDF data collected under controlled illumination could be taken for a small area of the site, while the large-scale scene could be photographed under a limited set of natural illumination conditions.

3.2.1 Data Collection and Registration

The site used in this work is composed entirely of marble, but its surfaces have been subject to different discoloration processes yielding significant reflectance variations. We located an accessible 30cm $\times$ 30cm surface that exhibited a range of coloration properties representative of the site. Since measuring the reflectance properties of this surface required controlled illumination conditions, we performed these measurements during our limited nighttime access to the site and used a BRDF measurement technique that could be executed quickly.

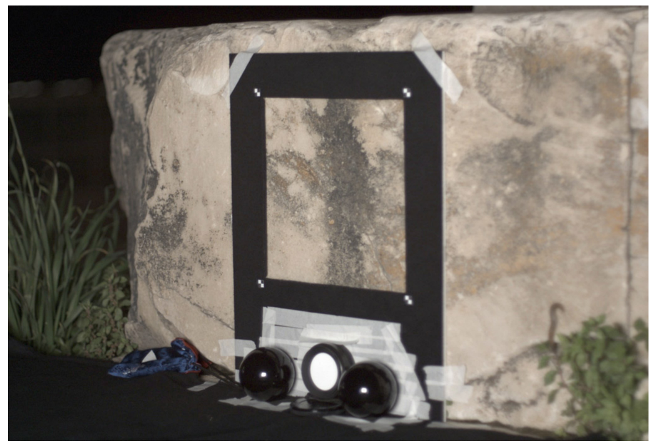


Figure 3: **BRDF Samples** are measured from a 30cm square region exhibiting a representative set of surface reflectance properties. The technique used a hand-held light source and camera and a calibration frame to acquire the BRDF data quickly.

The BRDF measurement setup (Fig. 3), includes a hand-held light source and camera, and uses a frame placed around the sample area that allows the lighting and viewing directions to be estimated from the images taken with the camera. The frame contains fiducial markers at each corner of the frame’s aperture from which the camera’s position can be estimated, and two glossy black plastic spheres used to determine the 3D position of the light source. Finally, the device includes a diffuse white reflectance standard parallel to the sample area for determining the intensity of the light source.

The light source chosen was a 1000W halogen source mounted in a small diffuser box, held approximately 3m from the surface. Our capture assumed that the surfaces exhibited isotropic reflection, requiring the light source to be moved only within a single plane of incidence. We placed the light source in four consecutive positions of 0°, 30°, 50°, 75°, and for each took hand-held photographs at a distance of approximately 2m from twenty directions distributed on the incident hemisphere, taking care to sample the specular and retroreflective directions with a greater number of observations. Dark clothing was worn to reduce stray illumination on the sample. The full capture process involving 83 photographs required forty minutes.

3.2.2 Data Analysis and Reflectance Model Fitting

To calculate the viewing and lighting directions, we first determined the position of the camera from the known 3D positions of the four fiducial markers using photogrammetry. With the camera positions known, we computed the positions of the two spheres by tracing rays from the camera centers through the sphere centers for several photographs, and calculated the intersection points of these rays. With the sphere positions known, we determined each light position by shooting rays toward the center of the light’s reflection in the

spheres. Reflecting the rays off the spheres, we find the center of the light source position where the two rays most nearly intersect. Similar techniques to derive light source positions have been used in [Masselus et al. 2002; Lensch et al. 2003].

From the diffuse white reflectance standard, the incoming light source intensity for each image could be determined. By dividing the overall image intensity by the color of the reflectance standard, all images were normalized by the incoming light source intensity. We then chose three different areas within the sampling region best corresponding to the different reflectance properties of the large-scale scene. These properties included a light tan area that is the dominant color of the site's surfaces, a brown color corresponding to encrusted biological material, and a black color representative of soot deposits. To track each of these sampling areas across the dataset, we applied a homography to each image to map them to a consistent orthographic viewpoint. For each sampling area, we then obtained a BRDF sample by selecting a 30x30 pixel region and computing the average RGB value. Had there been a greater variety of reflectance properties in the sample, a PCA analysis of the entire sample area as in [Lensch et al. 2003] could have been used.

To extrapolate the BRDF samples to a complete BRDF, we fit the BRDF to the Lafortune cosine lobe model (Eq. 1) in its isotropic form with three lobes for the Lambertian, specular, and retroreflective components. As suggested in [Lafortune et al. 1997], we then use a non-linear Levenberg-Marquardt optimization algorithm to determine the parameters of the model from our measured data. We first estimate the Lambertian component ρ_d, and then fit a retroreflective and a specular lobe separately before optimizing all the parameters in a single system. The resulting BRDFs (Fig. 5(b), back row) show mostly Lambertian reflectance with noticeable retroreflection and rough specular components at glancing angles. The brown area exhibited the greatest specular reflection, while the black area was the most retroreflective.

$$f(\vec{u},\vec{v}) = \rho_d + \sum_i [C_{xy,i}(u_x v_x + u_y v_y) + C_{z,i} u_z v_z]^{N_i} \qquad (1)$$

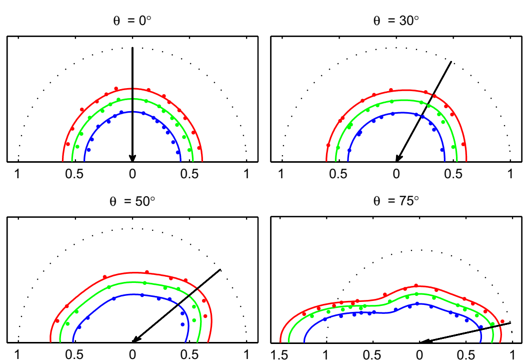
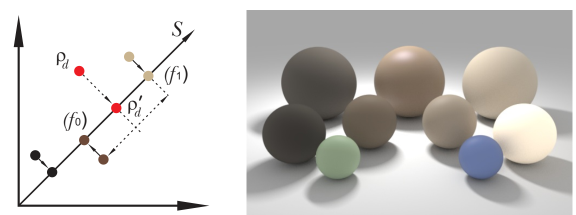


Figure 4: **BRDF Data and Fitted Reflectance Lobes** are shown for the RGB colors of the tan material sample for the four incident illumination directions. Only measurements within 15° of in-plane are plotted.

3.2.3 BRDF Inference

We wish to be able to make maximal use of the BRDF information obtained from our material samples in estimating the reflectance properties of the rest of the scene. The approach we take is informed by the BRDF basis construction technique from [Lensch et al. 2003], the data-driven reflectance model presented in [Matusik et al. 2003], and spatially-varying BRDF construction technique used in [Marschner et al. 2000]. Because the surfaces of the rest of the scene will often be seen in relatively few photographs under relatively diffuse illumination, the most reliable observation of a surface's reflectance is its Lambertian color. Thus, we form our problem as one of inferring the most plausible BRDF for a surface point given its Lambertian color and the BRDF samples available.

We first perform a principal component analysis of the Lambertian colors of the BRDF samples available. For RGB images, the number of significant eigenvalues will be at most three, and for our samples the first eigenvalue dominates, corresponding to a color vector of (0.688, 0.573, 0.445). We project the Lambertian color of each of our sample BRDFs onto the 1D subspace S (Fig. 5(a) formed by this eigenvector. To construct a plausible BRDF f for a surface having a Lambertian color ρ_d, we project ρ_d onto S to obtain the projected color ρ'_d. We then determine the two BRDF samples whose Lambertian components project most closely to ρ'_d. We form a new BRDF f' by linearly interpolating the Lafortune parameters (C_{xy}, C_z, N) of the specular and retroreflective lobes of these two nearest BRDFs f_0 and f_1 based on distance. Finally, since the retroflective color of a surface usually corresponds closely to its Lambertian color, we adjust the color of the retroflective lobe to correspond to the actual Lambertian color ρ_d rather than the projected color ρ'_d. We do this by dividing the retroreflective parameters C_{xy} and C_z by $(\rho'_d)^{1/N}$ and then multiplying by $(\rho_d)^{1/N}$ for each color channel, which effectively scales the retroreflective lobe to best correspond to the Lambertian color ρ_d. Fig. 5(b) shows a rendering with several BRDFs inferred from new Lambertian colors with this process.



(a) (b)

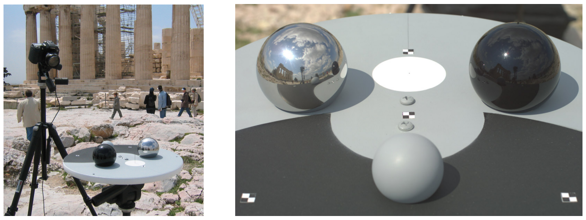
Figure 5: (a) Inferring a BRDF based on its Lambertian component ρ_d (b) Rendered spheres with measured and inferred BRDFs. Back row: the measured black, brown, and tan surfaces. Middle row: intermediate BRDFs along the subspace S. Front row: inferred BRDFs for materials with Lambertian colors not on S.

3.3 Natural Illumination Capture

Each time a photograph of the site was taken, we used a device to record the corresponding incident illumination within the environment. The lighting capture device was a digital camera aimed at three spheres: one mirrored, one shiny black, and one diffuse gray. We placed the device in a nearby accessible location far enough from the principal structure to obtain an unshadowed view of the sky, and close enough to ensure that the captured lighting would be sufficiently similar to that incident upon the structure. Measuring the incident illumination directly and quickly enabled us to make use of photographs taken under a wide range of weather including sunny, cloudy, and partially cloudy conditions, and also in changing conditions.

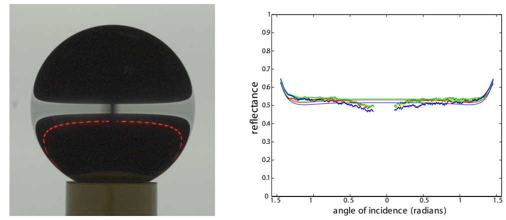
3.3.1 Apparatus Design

The lighting capture device is designed to measure the color and intensity of each direction in the upper hemisphere. A challenge in capturing such data for a natural illumination environment is that the sun's intensity can exceed that of the sky by over five orders of magnitude, which is significantly beyond the range of most digital



(a) (b)

Figure 6: (a) The incident illumination measurement device at its chosen location on the site (b) An incident illumination dataset.



(a) (b)

Figure 7: (a) Mirrored sphere photographed under an even ring of light, showing an increase in brightness at extreme grazing angles (the dark gap in the center is due to light source occluding the camera). (b) Fitted Fresnel reflectance curves.

image sensors. This dynamic range surpassing 17 stops also exceeds that which can conveniently be captured using high dynamic range capture techniques. Our solution was to take a limited dynamic range photograph and use the mirrored sphere to image the sky and clouds, the shiny black sphere to indicate the position of the sun (if visible), and the diffuse grey sphere to indirectly measure the intensity of the sun. We placed all three spheres on a board so that they could be photographed simultaneously (Fig. 6). We painted the majority of the board gray to allow a correct exposure of the device to be derived from the camera's auto-exposure function, but surrounded the diffuse sphere by black paint to minimize the indirect light it received. We also included a sundial near the top of the board to validate the lighting directions estimated from the black sphere. Finally, we placed four fiducial markers on the board to estimate the camera's relative position to the device.

We used a Canon D30 camera with a resolution of 2174×1446 pixels to capture images of the device. Since the site photography took place up to 300m from the incident illumination measurement station, we used a radio transmitter to trigger the device at the appropriate times. Though the technique we describe can work with a single image of the device, we set the camera's internal auto-exposure bracketing function to take three exposures for each shutter release at -2, +0, and +2 stops. This allowed somewhat higher dynamic range to better image brighter clouds near the sun, and to guard against any problems with the camera's automatic light metering.

3.3.2 Sphere Reflectance Calibration

To achieve accurate results, we calibrated the reflectance properties of the spheres. The diffuse sphere was painted with flat gray primer paint, which we measured as having a reflectivity of (0.30, 0.31, 0.32) in the red, green, and blue color channels. We further verified it to be nearly spectrally flat using a spectroradiometer. We also exposed the paint to several days of sunlight to verify its color stability. In the above calculations, we divide all pixel values by the sphere's reflectance, producing values that would result from a perfectly reflective white sphere.

We also measured the reflectivity of the mirrored sphere, which was made of polished steel. We measured this reflectance by using a robotic arm to rotate a rectangular light source in a circle around the sphere and taking a long-exposure photograph of the resulting reflection (Fig. 7(a)). We found that the sphere was 52% reflective at normal incidence, becoming more reflective toward grazing angles due to Fresnel reflection (Fig. 7(b)). From the measured reflectance data we used a nonlinear optimization to fit a Fresnel curve to the data, arriving at a complex index of refraction of $(2.40+2.98i, 2.40+3.02i, 2.40+3.02i)$ for the red, green, and blue channels of the sphere.

Light from a clear sky can be significantly polarized, particularly in directions perpendicular to the direction of the sun. In our work we assume that the surfaces in our scene are not highly specular, which makes it reasonable for us to disregard the polarization of the incident illumination in our reflectometry process. However, since Fresnel reflection is affected by the polarization of the incoming light, the clear sky may reflect either more or less brightly toward the grazing angles of the mirrored sphere than it should if it were photographed directly. To quantify this potential error, we photographed several clear skies reflected in the mirrored sphere and at the same time took hemispherical panoramas with a 24mm lens. Comparing the two, we found an RMS error of 5% in sky intensity between the sky photographed directly and the sky photographed as reflected in the mirrored sphere (Fig. 8). In most situations, however, unpolarized light from the sun, clouds, and neighboring surfaces dominates the incident illumination on surfaces, which minimizes the effect of this error. In Section 6, we suggest techniques for eliminating this error through improved optics.

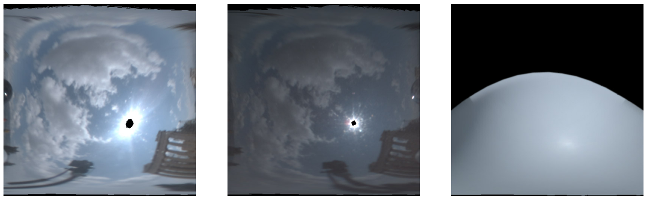
(a) (b)

Figure 8: (a) Sky photographed as reflected in a mirrored sphere (b) Stitched sky panorama from 16 24mm photographs, showing slightly different reflected illumination due to sky polarization.

3.3.3 Image Processing and Deriving Sun Intensity

To process these images, we assemble each set of three bracketed images into a single higher dynamic range image, and derive the relative camera position from the fiducial markers. The fiducial markers are indicated manually in the first image of each day and then tracked automatically through the rest of day, compensating for small motions due to wind. Then, the reflections in both the mirrored and shiny black spheres are transformed to 512×512 images of the upper hemisphere. This is done by forward-tracing rays from the camera to the spheres (whose positions are known) and reflecting the rays into the sky, noting for each sky point the corresponding location on the sphere. The image of the diffuse sphere is also mapped to the sky's upper hemisphere, but based on the sphere's normals rather the reflection vectors. In the process, we also adjust for the reflectance properties of the spheres as described in Section 3.3.2, creating the images that would have been produced by spheres with unit albedo. Examples of these unwarped images are shown in Fig. 9.

If the sun is below the horizon or occluded by clouds, no pixels in the mirrored sphere image will be saturated and it can be used directly as the image of the incident illumination. We can validate the accuracy of this incident illumination map by rendering a synthetic diffuse image D' with this lighting and checking that it is consistent

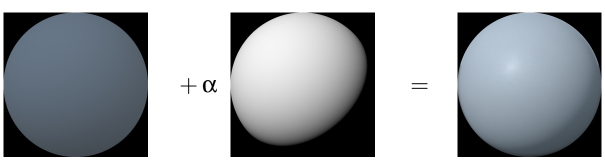


(a) (b) (c)

Figure 9: Sphere images unwarped to the upper hemisphere for the (a) Mirrored sphere (b) Shiny black sphere (c) Diffuse sphere D. Saturated pixels are shown in black.

with the appearance of the actual diffuse sphere image D. As described in [Miller and Hoffman 1984], this lighting operation can be performed using a diffuse convolution filter on the incident lighting environment. For our data, the root mean square illumination error for our diffuse sphere images agreed to within 2% percent for a variety of environments.

When the sun is visible, it usually saturates a small region of pixels in the mirrored sphere image. Since the sun's bright intensity is not properly recorded in this region, performing a diffuse convolution of the mirrored sphere image will produce a darker image than actual appearance of the diffuse sphere (Compare D' to D in Fig. 10). In this case, we reconstruct the illumination from the sun as follows. We first measure the direction of the sun as the center of the brightest spot reflected in the shiny black sphere (with its darker reflection, the black sphere exhibits the most sharply defined image of the sun.) We then render an image of a diffuse sphere $D^\star$ lit from this direction of illumination, using a unit-radiance infinite light source 0.53 degrees in diameter to match the subtended angle of the real sun. Such a rendering can be seen in the center of Figure 10.



D' $D^\star$ D

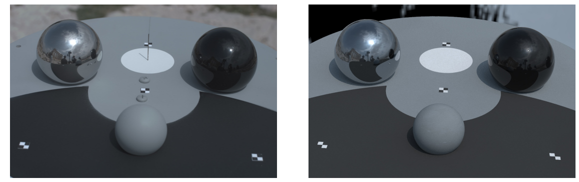
Figure 10: Solving for sun intensity α based on the appearance of the diffuse sphere D and the convolved mirrored sphere D'.

We can then write that the appearance of the real diffuse sphere D should equal the sphere lit by the light captured in the mirrored sphere D' plus an unknown factor α times the sphere illuminated by the unit sun $D^\star$, i.e.

$$D' + \alpha D^\star = D$$

Since there are many pixels in the sphere images, this system is overdetermined, and we compute the red, green, and blue components of α using least squares as $\alpha D^\star \approx D - D'$. Since $D^\star$ was rendered using a unit radiance sun, α indicates the radiance of the sun disk for each channel. For efficiency, we keep the solar illumination modeled as the directional disk light source, rather than updating the mirrored sphere image M to include this illumination. As a result, when we create renderings with the measured illumination, the solar component is more efficiently simulated as a direct light source.

We note that this process does not reconstruct correct values for the remaining saturated pixels near the sun; the missing illumination from these regions is effectively added to the sun's intensity. Also, if the sun is partially obscured by a cloud, the center of the saturated region might not correspond precisely to the center of the sun. However, for our data the saturated region has been sufficiently small that this error has not been significant. Fig. 11 shows a lighting capture dataset and a comparison rendering of a model of the capture apparatus, showing consistent captured illumination.



(a) (b)

Figure 11: **(a)** Real photograph of the lighting capture device **(b)** Synthetic rendering of a 3D model of the lighting capture device to validate the lighting measurements.

3.4 3D Scanning

To obtain 3D geometry for the scene, we used a time-of-flight panoramic range scanner manufactured by Quantapoint, Inc, which uses a 950nm infrared laser measurement component [Hancock et al. 1998]. In high resolution mode, the scanner acquires scans of 18,000 by 3,000 3D points in 8 minutes, with a maximum scanning range of 40m and a field of view of 360 degrees horizontal by 74.5 degrees vertical. Some scans from within the structure were scanned in low-resolution, acquiring one-quarter the number of points. The data returned is an array of (x,y,z) points as well as a 16-bit monochrome image of the infrared intensity returned to the sensor for each measurement. Depending on the strength of the return, the depth accuracy varied between 0.5cm and 3cm. Over five days, 120 scans were acquired in around the site, of which 53 were used to produce the model in this paper.

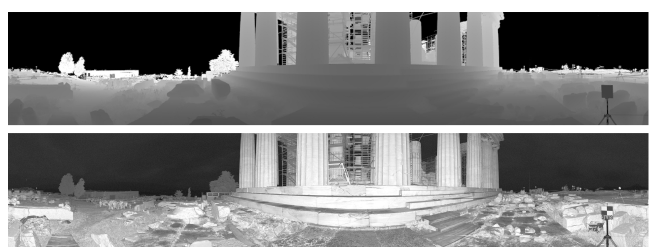


Figure 12: Range measurements, shaded according to depth (top), and infrared intensity return (bottom) for one of 53 panoramic laser scans used to create the model. A fiducial marker appears at right.

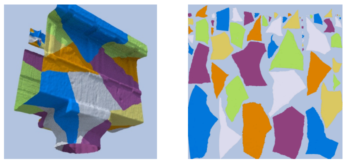
3.4.1 Scan Processing

Our scan processing followed the traditional process of alignment, merging, and decimation. Scans from outside the structure were initially aligned during the scanning process through the use of checkerboard fiducial markers placed within the scene. After the site survey, the scans were further aligned using an iterative closest point (ICP) algorithm [Besl and McKay 1992; Chen and Medioni 1992] implemented in the CNR-Pisa 3D scanning toolkit [Callieri et al. 2003]. To speed the alignment process, three or more subsections of each scan corresponding to particular scene areas were cropped out and used to determine the alignment for the entire scan.

For merging, the principal structure of the site was partitioned into an $8 \times 17 \times 5$ lattice of voxels 4.3 meters on a side. For convenience, the grid was chosen to align with the principal architectural features of the site. The scan data within each voxel was merged by a volumetric merging algorithm [Curless and Levoy 1996] also from the CNR-Pisa toolkit using a volumetric resolution of 1.2cm.

Finally, the geometry of a $200m \times 200m$ area of surrounding terrain was merged as a single mesh with a resolution of 40cm.

Several of the merged voxels contained holes due to occlusions or poor laser return from dark surfaces. Since such geometric inconsistencies would affect the reflectometry process, they were filled using semi-automatic tools with Geometry Systems, Inc. GSI Studio software (Fig. 13).



(a) (b)

Figure 13: (a) Geometry for a voxel colored according to texture atlas regions (b) The corresponding texture atlas.

Our reflectometry technique determines surface reflectance properties which are stored in texture maps. We used a texture atlas generator [Graphite 2003] based on techniques in [Lévy et al. 2002] to generate a 512×512 texture map for each voxel. Then, a low-resolution version of each voxel was created using the Qslim software [QSlim 1999] based on techniques in [Garland and Heckbert 1998]. This algorithm was chosen since it preserves edge polygons, allowing low resolution and high resolution voxels to connect without seams, and since it preserves the texture mapping space, allowing the same texture map to be used for either the high or low resolution geometry.

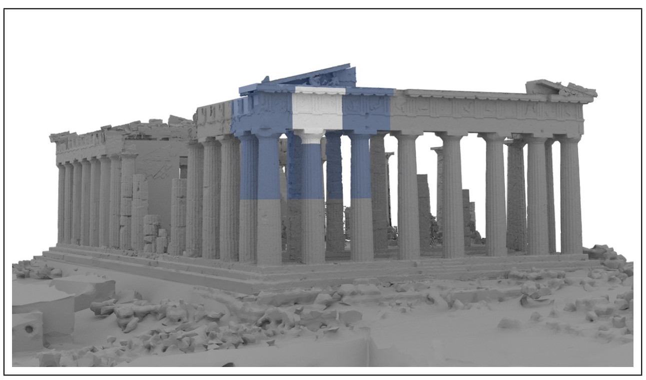


Figure 14: Complete model assembled from the 3D scanning data, including low-resolution geometry for the surrounding terrain. High and medium resolution voxels used for the multiresolution reflectance recovery are indicated in white and blue.

The complete high-resolution model of the main structure used 89 million polygons in 442 non-empty voxels (Figure 14). The lowest-resolution model contained 1.8 million polygons, and the surrounding environment used 366K polygons.

3.5 Photograph Acquisition and Alignment

Images were taken of the scene from a variety of viewpoints and lighting conditions using the Canon 1Ds camera. We used a semi-automatic process to align the photographs to the 3D scan data. We began by marking approximately 15 point correspondences between each photo and the infrared intensity return image of one or more 3D scans, forming a set of 2D to 3D correspondences. From this we estimated the camera pose using Intel's OpenCV library, achieving a mean alignment error of between 1 and 3 pixels at 4080×2716 pixel resolution. For photographs with higher alignment error, we use an automatic technique to refine the alignment based on comparing the structure's silhouette in the photograph to the model's silhouette seen through the recovered camera as in [Lensch et al. 2001], using a combination of gradient-descent and simulated annealing.

4 Reflectometry

In this section we describe the central reflectometry algorithm used in this work. The basic goal is to determine surface reflectance properties for the scene such that renderings of the scene under captured illumination match photographs of the scene taken under that illumination. We adopt an inverse rendering framework as in [Boivin and Gagalowicz 2002; Debevec 1998] in which we iteratively update our reflectance parameters until our renderings best match the appearance of the photographs. We begin by describing the basic algorithm and continue by describing how we have adapted it for use with a large dataset.

4.1 General Algorithm

The basic algorithm we use proceeds as follows:

1. Assume initial reflectance properties for all surfaces
2. For each photograph:
   (a) Render the surfaces of the scene using the photograph's viewpoint and lighting
   (b) Determine a reflectance update map by comparing radiance values in the photograph to radiance values in the rendering
   (c) Compute weights for the reflectance update map
3. Update the reflectance estimates using the weightings from all photographs
4. Return to step 2 until convergence

For a pixel's Lambertian component, the most natural update for a pixel's Lambertian color is to multiply it by the ratio of its color in the photograph to its color in the corresponding rendering. This way, the surface will be adjusted to reflect the correct proportion of the light. However, the indirect illumination on the surface may change in the next iteration since other surfaces in the scene may also have new reflectance properties, requiring further iterations.

Since each photograph will suggest somewhat different reflectance updates, we weight the influence a photograph has on a surface's reflectance by a confidence measure. For one weight, we use the cosine of the angle at which the photograph views the surface. Thus, photographs which view surfaces more directly will have a greater influence on the estimated reflectance properties. As in traditional image-based rendering (e.g. [Buehler et al. 2001]), we also downweight a photograph's influence near occlusion boundaries. Finally, we also downweight an image's influence near large irradiance gradients in the photographs since these typically indicate shadow boundaries, where small misalignments in lighting could significantly affect the reflectometry.

In this work, we use the inferred Lafortune BRDF models described in Sec. 3.2.3 to create the renderings, which we have found to also converge accurately using updates computed in this manner. This convergence occurs for our data since the BRDF colors of the Lambertian and retroreflective lobes both follow the Lambertian color, and since for all surfaces most of the photographs do not observe a specular reflection. If the surfaces were significantly more specular, performing the updates according to the Lambertian component alone would not necessarily converge to accurate reflectance estimates. We discuss potential techniques to address this problem in the future work section.

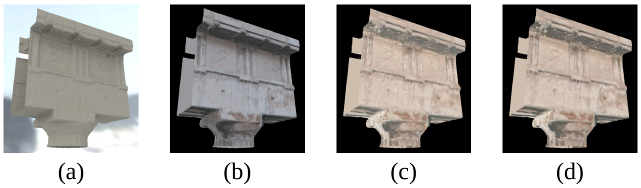


Figure 15: **Computing reflectance properties for a voxel (a)** Iteration 0: 3D model illuminated by captured illumination, with assumed reflectance properties **(b)** Photograph taken under the captured illumination projected onto the geometry **(c)** Iteration 1: New reflectance properties computed by comparing (a) to (b). **(d)** Iteration 2: New reflectance properties computed by comparing a rendering of (c) to (b).

4.2 Multiresolution Reflectance Solving

The high-resolution model for our scene is too large to fit in memory, so we use a multiresolution approach to computing the reflectance properties. Since our scene is partitioned into voxels, we can compute reflectance property updates one voxel at a time. However, we must still model the effect of shadowing and indirect illumination for the rest of the scene. Fortunately, lower-resolution geometry can work well for this purpose. In our work, we use full-resolution geometry (approx. 800K triangles) for the voxel being computed, medium-resolution geometry (approx. 160K triangles) for the immediately neighboring voxels, and low-resolution geometry (approx. 40K triangles) for the remaining voxels in the scene. (The surrounding terrain is kept at a low resolution of 370K triangles.) The multiresolution approach results in over a 90% data reduction in scene complexity during the reflectometry of any given voxel.

Our global illumination rendering system was originally designed to produce 2D images of a scene for a given camera viewpoint using path tracing [Kajiya 1986]. We modified the system to include a new function for computing surface radiance for any point in the scene radiating toward any viewing position. This allows the process of computing reflectance properties for a voxel to be done by iterating over the texture map space for that voxel. For efficiency, for each pixel in the voxel's texture space, we cache the position and surface normal of the model corresponding to that texture coordinate, storing these results in two additional floating-point texture maps.

1. Assume initial reflectance properties for all surfaces
2. For each voxel V:
   (a) Load V at high resolution, V's neighbors at medium resolution, and the rest of the model at low resolution
   (b) For each pixel p in V's texture space
      i. For each photograph I:
         A. Determine if p's surface is visible to I's camera. If not, break. If so, determine the weight for this image based on the visibility angle, and note pixel q in I corresponding to p's projection into I.
         B. Compute the radiance l of p's surface in the direction of I's camera under I's illumination
         C. Determine an updated surface reflectance by comparing the radiance in the image at q to the rendered radiance l.
      ii. Assign the new surface reflectance for p as the weighted average of the updated reflectances from each I
3. Return to step 2 until convergence

Figure 16: Estimated surface reflectance properties for an East facade column in texture atlas form.

Figure 15 shows this process of computing reflectance properties for a voxel. Fig. 15(a) shows the 3D model with the assumed initial reflectance properties illuminated by a captured illumination environment. Fig. 15(b) shows the voxel texture-mapped with radiance values from a photograph taken under the captured illumination in (a). Comparing the two, the algorithm determines updated surface reflectance estimates for the voxel, shown in Fig. 15(c). The second iteration compares an illuminated rendering of the model with the first iteration's inferred BRDF properties to the photograph, producing new updated reflectance properties shown in 15(d). For this voxel, the second iteration produces a darker Lambertian color for the underside of the ledge, which results from the fact that the *black* BRDF sample measured in Section 3.2 has a higher proportion of retroreflection than the average reflectance. The second iteration is computed with a greater number of samples per ray, producing images with fewer noise artifacts. Reflectance estimates for three voxels of a column on the East Facade are shown in texture atlas form in Fig. 16. Reflectance properties for all voxels of the two Facades are shown in Figs. 1(b) and 19(d). For our model, the third iteration produces negligible change from the second, indicating convergence.

5 Results

We ran our reflectometry algorithm on the 3D scan dataset, computing high-resolution reflectance properties for the two westmost and eastmost rows of voxels. As input to the algorithm, we used eight photographs of the East Facade (e.g. Fig. 1 (a)) and three of the West Facade, in an assortment of sunny, partly cloudy, and cloudy lighting conditions. Poorly scanned scaffolding which had been removed from the geometry was replaced with approximate polygonal models in order to better simulate the illumination transport within the structure. The reflectance properties of the ground were assigned based on a sparse sampling of ground truth measurements made with a MacBeth chart. We recovered the reflectance properties in two iterations of the reflectometry algorithm. For each iteration of the reflectometry, the illumination was simulated with two indirect bounces using the inferred Lafortune BRDFs. Computing the reflectance for each voxel required an average of ten minutes.

Figs. 1(b) and 19(c) show the computed Lambertian reflectance colors for the East and West Facades, respectively. Recovered texture atlas images for three voxels of the East column second from left are shown in Fig. 16. The images show few shading effects, suggesting that the maps have removed the effect of the illumination in the photographs. The subtle shading observable toward the back sides of the columns is likely the result of incorrectly computed indirect illumination due to the remaining discrepancies in the scaffolding.

Figs. 19(a) and (b) show a comparison between a real photograph and a synthetic global illumination rendering of the East Facade under the lighting captured for the photograph, indicating a consistent appearance. The photograph represents a significant variation in the lighting from all images used in the reflectometry

dataset. Fig. 19(d) shows a rendering of the West Facade model under novel illumination and viewpoint. Fig. 19(e) shows the East Facade rendered under novel artificial illumination. Fig. 19(f) shows the East Facade rendered under sunset illumination captured from a different location than the original site.

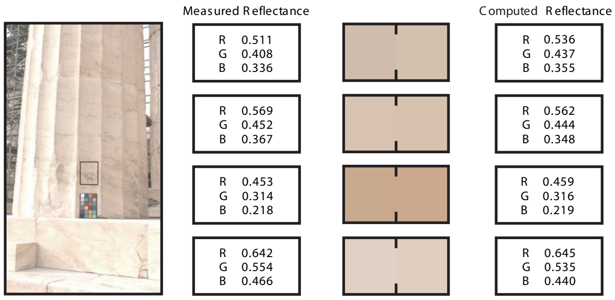


Figure 17: Left: Acquiring a ground truth reflectance measurement. Right: Reflectance comparisons for four locations on the East Facade

To provide a quantitative validation of the reflectance measurements, we directly measured the reflectance properties of several surfaces around the site using a MacBeth color checker chart. Since the measurements were made at normal incidence and in diffuse illumination, we compared the results to the Lambertian lobe directly, as the specular and retroreflective lobes are not pronounced under these conditions. The results tabulated in Fig. 17 show that the computed reflectance largely agreed with the measured reflectance samples, with a mean error of $(2.0\%, 3.2\%, 4.2\%)$ for the red, green, and blue channels.

6 Discussion and Future Work

Our experiences with the process suggest several avenues for future work. Most importantly, it would be of interest to increase the generality of the reflectance properties which can be estimated using the technique. Our scene did not feature surfaces with sharp specularity, but most scenes featuring contemporary architecture do. To handle this larger gamut of reflectance properties, one could imagine adapting the BRDF clustering and basis formation techniques in [Lensch et al. 2003] to photographs taken under natural illumination conditions. Our technique for interpolating and extrapolating our BRDF samples is relatively simplistic; using more samples and a more sophisticated analysis and interpolation as in [Matusik et al. 2003] would be desirable. A challenge in adapting these techniques to natural illumination is that observations of specular behavior are less reliable in natural illumination conditions. Estimating reflectance properties with increased spectral resolution would also be desirable.

In our process the photographs of the site are used only for estimating reflectance, and are not used to help determine the geometry of the scene. Since high-speed laser scan measurements can be noisy, it would be of interest to see if photometric stereo techniques as in [Rushmeier et al. 1998] could be used in conjunction with natural illumination to refine the surface normals of the geometry. [Yu and Malik 1998] for example used photometric stereo from different solar positions to estimate surface normals for a building's environment; it seems possible that such estimates could also be made given three images of general incident illumination with or without the sun.

Our experience calibrating the illumination measurement device showed that its images could be affected by sky polarization. We tested the alternative of using an upward-pointing fisheye lens to image the sky, but found significant polarization sensitivity toward the horizon as well as undesirable lens flare from the sun. More successfully, we used a 91% reflective aluminum-coated hemispherical lens and found it to have less than 5% polarization sensitivity, making it suitable for lighting capture. For future work, it might be of interest to investigate whether sky polarization, explicitly captured, could be leveraged in determining a scene's specular parameters [Nayar et al. 1997].

Finally, it could be of interest to use this framework to investigate the more difficult problem of estimating a scene's reflectance properties under unknown natural illumination conditions. In this case, estimation of the illumination could become part of the optimization process, possibly by fitting to a principal component model of measured incident illumination conditions.

7 Conclusion

We have presented a process for estimating spatially-varying surface reflectance properties of an outdoor scene based on scanned 3D geometry, BRDF measurements of representative surface samples, and a set of photographs of the scene under measured natural illumination conditions. Applying the process to a real-world archaeological site, we found it able to recover reflectance properties close to ground truth measurements, and able to produce renderings of the scene under novel illumination consistent with real photographs. The encouraging results suggest further work be carried out to capture more general reflectance properties of real-world scenes using natural illumination.

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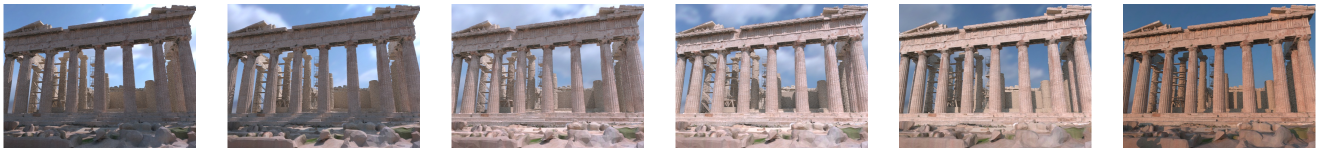

Figure 18: The East Facade model rendered under novel natural illumination conditions at several times of day.

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Figure 19: **(a)** A real photograph of the East Facade, with recorded illumination **(b)** Rendering of the model under the illumination recorded for (a) using inferred Lafortune reflectance properties **(c)** A rendering of the West Facade from a novel viewpoint under novel illumination. **(d)** Front view of computed surface reflectance for the West Facade (the East is shown in Fig. 1(b)). A strip of unscanned geometry above the pediment ledge has been filled in and set to the average surface reflectance. **(e)** Synthetic rendering of the West Facade under a novel artificial lighting design. **(f)** Synthetic rendering of the East Facade under natural illumination recorded for another location. In these images, only the front two rows of outer columns are rendered using the recovered reflectance properties; all other surfaces are rendered using the average surface reflectance.

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MILITARY PYROTECHNICS.

This handbook is issued with the understanding that it shall at all times be given the care accorded confidential information; that no portion of it shall be published by paraphrase or otherwise, and that it shall be returned to the office of the Chief of Ordnance when the person to whom it is issued leaves the military service of the United States.

The facts have been collected by W. N. Dickinson from the official records, cablegrams, and reports, and have been supplemented by information obtained from officers in the several branches of the military establishment, whose services were rendered both in the United States and with the American Expeditionary Forces.

The matter included in the present pamphlet was originally compiled in conjunction with the "History of Trench Warfare Matériel" and references to it will be found in that history.

For convenience in publication and in use, it has been separated into the present form.

C. C. Williams,
Maj. Gen., Chief of Ordnance, U. S. A.

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MILITARY PYROTECHNICS.

CHAPTER I.

PYROTECHNICS.

Military pyrotechnics are employed for communication and illumination.

In the former of these two uses, they play their part in the great system of understanding on the basis of which modern warfare is waged. While included within the trench warfare matériel, pyrotechnics are employed also in open warfare, and both from the ground and from planes in the air.

In an unobtrusive corner in the National Museum in Washington is a large war map, brilliantly lighted and confronted by four conference chairs. On this map are lines and tabs indicating the entire Western Front with the positions of the several armies on both sides of the line at the time of the signing of the armistice. Indicated thereon are the headquarters, the reserve units, and the distribution of the troops on the fighting front by divisions. This represents the concentration of information as to the disposition of the various divisions, as obtained by telegraph, telephone, and by dispatches.

Apart from the reserves, it represents the information which was constantly being gathered through the intermediate channels from the fighting front. This front might consist of long lines of trenches, open country, woods, mountains, or waterways. The front might be quiet or in vigorous action, and the difficulties of establishing and maintaining contact for immediate communication varied with the degree of action, with weather conditions and the time of night or day. In time of movement instant information was of the utmost importance. On it depended the opportunity for surprise, knowledge of the need for support or the necessity for change in plans. Battle without chaos is dependent upon complete understanding and it is this understanding only which prevents chaos. The information to establish this understanding was conveyed by ground telegraph, wireless telegraph, telephone, buzzerphone, written dispatches, messengers on cycles and motor cycles, Cavalry riders, runners, electric flashlights or other lights or projectors using either intermittent flashes or color, reflection of the sun in mirrors, whistles, horns, bugles, message grenades, flag signals, arm movements, dogs, carrier pigeons, photographs, messages dropped from airplanes, panels laid on the ground and observed from airplanes, and pyrotechnics.

It was necessary that the information be transmitted from the front to the rear, from the rear to the front, and laterally between units cooperating in the same action. Observation posts, balloons, airplanes, and practically every part of the field were involved in this necessity for communication. Reliance could not be placed upon one method only of communication, as any one method might be rendered impotent. Wires might be cut, a balloon or an airplane brought down, messengers killed or cut off, and observation posts destroyed. One of the principles in warfare is that an observation post which is not fired upon is not necessarily one which has not been located. It is indeed considered best to leave unmolested stations which have been located in order that the enemy may not construct others better protected or disguised. It often happens that these stations are not destroyed until the day when it will be really advantageous to deprive the enemy of their use, as in the case of attack.

In the forward areas a complete understanding must exist between each Infantry unit on the front and its supporting Artillery, the Air Service, Trench Mortar batteries, the Chemical Warfare units, the sappers who are about to explode mines, and with the plans and operations of the units immediately adjoining. As actions are now planned and carried out, the establishment of uniform time for the setting of watches to permit of the carrying out of orders on exact schedule is of the utmost importance. With troops widely scattered through a labyrinth of trenches, shell holes, woods, ravines, and protected positions, this establishment of time must take place, in so far as possible, from a single source and at a moment sufficiently close to the major operation to reduce to a minimum any errors resulting from variation in the functioning of individual timepieces. If this complete understanding is not had, units fail to cooperate or may be subjected to the fire of their own artillery, or the artillery, machine gun, or mortar fire of adjoining units.

This whole subject of communication and intercommunication is treated broadly under the tactical instructions in "Liaison for all Arms."

Pyrotechnics are visible (more or less) either by night or by day, with the exception that those with yellow or red smoke and flag rockets can not always be seen to advantage at night. Their meaning may be conveyed by the form, color, or numerical distribution of burst. When used as ground signals it will be observed that they are more liable to be employed in the very forefront of the action at a time when seconds count and when the lives of many men or the success of an individual movement depends upon their proper functioning. When it is recalled that these pyrotechnics when in the possession of forward units may be carried through trenches knee-deep in water, through a deluge of rain, or across marshy country, it

will be clear that their protection from dampness is imperative. They may be fired at night, and more frequently are fired at night than by day, and their distinguishing markings therefore should be readily determinable by touch as well as by sight. One signal means one thing and another signal means another thing, and the wrong signal would convey incorrect information and cause confusion and might bring disaster. Protection from dampness and clear marking are features to be dwelt upon.

Signal rockets may be sent up from carefully aimed troughs or tubes, or may be sent up without fixtures of any kind, and a difference in the course of the rocket might bring the burst over a unit different from that by whom it had been discharged, or at a point which would cause confusion in the mind of the watcher as to the unit to which the signal applied. For this reason it was necessary in our own pyrotechnics to take a lesson from the French and attach a smoke tracer to rockets, which, while it lessened the height to which the rocket could be thrown, indicated the source from which the rocket had been sent.

The question of height also has a bearing upon the chance of confusing the signals discharged from ground units and from airplanes, which may burst along substantially the same line of front, but whose meaning is intended for different watchers and for different purposes, hence the establishment of different altitudes of burst for ground and airplane signals.

When friendly and enemy front lines are in close proximity, it is manifestly difficult and frequently impossible for watchers to determine whether rockets sent up have emanated from a friendly or from an enemy source, and hence the frequent change in the types of rockets employed by troops on different nights.

Under favorable conditions, ground pyrotechnics may establish an understanding with friendly airplanes or artillery, indicate position of units which may or may not be cut off from other means of communication, call for a barrage, give warning of a gas attack, indicate that ammunition is running low, that friendly artillery shell are raining on our own troops, or convey practically any other information that may be agreed upon in the code.

From the trenches where the ground signal pyrotechnics were most frequently employed, apart from establishing communication with airplanes and lining out the position, their use was practically confined to signaling from the front to the rear, and the code was finally confined to very few signals. This was due to the uncertainty in the determination of the unit from which the signal emanated, the lack of certainty of proper functioning of the signal as a result of chemical or physical changes in the signal, and the practice of the enemy of observing the signal and then repeating that signal at

different parts of his or near-by lines for the purpose of confusing our signal officers. Military pyrotechnic signals have a place, but for use along an entrenched front with the enemy close at hand there are distinct practical limitations to their employment.

While the outline of forward positions is perhaps more frequently indicated by means of panels laid upon the ground and observed by friendly airplanes, such outline of position may be indicated by the burning of Bengal flares—position lights—or by the use of signal cartridges discharged from Very pistols or VB signal projectors employed with rifles.

Pyrotechnics also have their use in providing a sudden illumination at night over an area which it is desired to guard against surprise attack or in revealing an enemy who may be effecting a movement or operation under the cover of darkness.

Smoke torches, which also come under the head of pyrotechnics, may be employed for concealment of the movements or operations of friendly troops.

Military pyrotechnics are also employed largely in the air service for the direction of planes, the establishment of communications with forward ground units or with watchers, for purposes of illumination, for the establishment of understanding with the home field as to whether it is clear for night landing, and by means of wing tip flares for providing temporary illumination of the ground at night to permit of landing.

For use from airplanes the signals usually are discharged from Very pistols, and frequent use of the Very pistol is also made in discharging pyrotechnic signals from the ground.

GENERAL NARRATIVE.

Prior to the present conflict, the following pyrotechnics had been developed for the United States Army: Rockets by the Signal Corps; position lights by the Engineering Corps; Frankford Arsenal rifle illuminating grenades by the Army Ordnance Department; and the Very pistol cartridge, which was in production by the Navy and which had been issued in very limited quantities to the Signal Corps of the Army.

The rockets employed by the Signal Corps were red, green, white, yellow smoke, and sequence rocket (since discarded), all with parachute. The comparatively small elevation attained by these rockets was between 200 and 400 feet, and the colors were indistinct and the functioning uncertain.

The white hand position light, which had been developed by the Engineering Corps, would burn for about one minute with a candlepower of 12,000.

The Frankford Arsenal rifle grenade, illuminating, was both unsatisfactory and costly.

The Very pistol cartridge, manufactured by the Navy and issued in small quantities to the Signal Corps, was No. 10 gauge. About 3,000,000 cartridges had been manufactured, and hence the manufacturers were in possession of the necessary molds and had obtained experience in producing the Very star. The formula of the composition used by the Navy was not, however, considered stable by the Army Ordnance Department, and the degree of visibility of the cartridge was regarded as unsatisfactory.

In addition to the above there had been more or less developed a smoke torch for signaling purposes, a 35-millimeter cartridge for purposes of aviation signaling, the airplane flare, and the wing tip flare.

In the design of the smoke torch, the British type had been followed and some minor changes made to meet the requirements of the American chemical market.

The 35-millimeter cartridge and its pistol were adopted from the French program and included a variety of signals which were to be used in the Aviation Service.

The airplane flare was to be used from an airplane, illuminating the underlying terrain, and required much experimental work. The type was a slightly modified French Michelin flare.

The wing tip flare is attached to the wings of an airplane, and is used as an illuminant to facilitate night landing. It takes its name from its location on the lower side of the wings of an airplane. The origin of the design was the Holt landing flare adopted by the British.

It will appear that pyrotechnics were to be furnished both for ground work and for the Air Service.

For the use of American troops in France, the early supply of pyrotechnics was obtained abroad.

It was not until September 27, 1917, by General Order No. 128, that the design of all signaling and illuminating devices of a pyrotechnic nature was assigned to the Army Ordnance Department.

On March 28, 1918 (cablegram 796–5H), Gen. Pershing cabled directing that the entire French system of pyrotechnics be adopted. The following signals were therefore adopted:

Signal star rocket, Mark I, white, 1, 3, and 6 stars	2 pounds, 20 inches long.
Signal star rocket, Mark I, red, 1, 3, and 6 stars	
Signal star rocket, Mark I, green 1, 3, and 6 stars	
Signal parachute rocket, Mark I, red	
Signal parachute rocket, Mark I, green	
Signal parachute rocket, Mark I, white caterpillar	
Signal parachute rocket, Mark I, red caterpillar	
Signal parachute rocket, Mark I, green caterpillar	
Signal parachute rocket, Mark I, yellow smoke	
Signal parachute rocket, Mark I, flag	
Signal parachute rocket, Mark I, red smoke	
Signal illuminating rocket, Mark I, white parachute	

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VB star cartridge, Mark I, white, 1, 3, and 6 stars	4½ inches to 7 inches long; 0.7 to 0.9 pound.
VB star cartridge, Mark I, red, 1, 3, and 6 stars	
VB star cartridge, Mark I, green, 1, 3, and 6 stars	
VB parachute cartridge, Mark I, white	
VB parachute cartridge, Mark I, red	
VB parachute cartridge, Mark I, green	
VB parachute cartridge, Mark I, white caterpillar	
VB parachute cartridge, Mark I, red caterpillar	
VB parachute cartridge, Mark I, green caterpillar	
VB parachute cartridge, Mark I, yellow smoke	
Very star cartridge, Mark I, 25-mm., white, 1, 3, and 6 stars	6 inches long; 0.2 to 0.4 pound.
Very star cartridge, Mark I, 25-mm., red, 1, 3, and 6 stars	
Very star cartridge, Mark I, 25-mm., green, 1, 3, and 6 stars	
Very parachute cartridge, Mark I, 25-mm., white	6 inches long; 0.4 pound.
Very parachute cartridge, Mark I, 25-mm., red	
Very parachute cartridge, Mark I, 25-mm., green	
Very parachute cartridge, Mark I, 25-mm., white caterpillar	
Very parachute cartridge, Mark I, 25-mm., red caterpillar	
Very parachute cartridge, Mark I, 25-mm., green caterpillar	
Very parachute cartridge, Mark I, 25-mm., yellow smoke	
35-mm. signal cartridge, Mark I, aviation, white, 1, 2, 3, and 6 stars	4 inches to 6 inches long; 0.5 to 0.6 pound.
35-mm. signal cartridge, Mark I, aviation, red, 1 and 6 stars	
35-mm. signal cartridge, Mark I, aviation, white caterpillar, parachute	
35-mm. signal cartridge, Mark I, aviation, yellow smoke, parachute	
35-mm. signal cartridge, Mark I, aviation, yellow, 1 and 6 stars	
35-mm. signal cartridge, Mark I, aviation, message	
35-mm. signal cartridge, Mark I, aviation, red smoke, parachute	
35-mm. signal cartridge, Mark I, aviation, changing color—red to green	
35-mm. signal cartridge, Mark I, aviation, changing color—red to white	
35-mm. signal cartridge, Mark I, aviation, changing color—green to red	
35-mm. signal cartridge, Mark I, aviation, changing color—green to white	
35-mm. signal cartridge, Mark I, aviation, changing color—white to red	
35-mm. signal cartridge, Mark I, aviation, changing color—white to green	
35-mm. signal cartridge, Mark I, aviation, green, 1 and 6 stars	
Wing tip flare, Mark I, white and red	4 inches long, 0.6 pound.
Airplane flare, Mark I	4 feet long, 36 pounds.
Position light, Mark I, white, ground	3 inches long, 0.4 pound.
Position light, Mark I, red, ground	
Position light, Mark I, green, ground	
Position light, Mark II, white, hand	10 inches long, 0.8 pound.
Smoke torch, Mark I	6 inches long, 0.4 pound.

35-mm. signal pistol, Mark I, aviation	10 inches long, 2 pounds.
Very signal pistol, 25-mm., Mark IV	8 inches long, 2 pounds.

The adoption of the French pyrotechnic system necessitated the change from the No. 10 gauge Very pistol to the 25-millimeter Very pistol.

On April 1, 1918, a letter from the Trench Warfare Division of the American Expeditionary Forces specified the quantity requirements as then viewed to complete the year 1918. In this letter appeared the statement:

> Negotiations are in progress for the purchase from the French of six months' supply from April 1, and the indications are that our demands will be granted and that a further supply sufficient for the balance of the year will also be available from the French if it should be necessary.

Following the decision to adopt the entire French system of pyrotechnics, the preparation of drawings and specifications for manufacture in the United States to correspond with the French system of pyrotechnics was delayed due to the lack of information in the United States of the French requirements of design and details of manufacture. No French drawings nor specifications, and but few samples had been received. Following a number of requests, further samples were received and drawings and specifications were completed shortly thereafter.

Until the middle of the summer of 1918, the status of the pyrotechnic supply program was considered satisfactory. However, during August and September of 1918, the new requirements to June, 1919, were issued, and it became immediately evident that existing facilities were inadequate to produce the large quantities required, involving some 128,000,000 pieces, to be delivered at the rate of approximately 430,000 per diem.

A survey of production possibilities was made, and, based upon the results, the Trench Warfare Board submitted recommendations to the Chief of Ordnance on September 26, 1918, covering the development of the existing private plant facilities in the United States to handle the more complex pyrotechnic items and the erection of Government plants to manufacture the simpler items. The armistice was signed before these recommendations were approved. The Plant Facilities Section also considered the erection of two or more pyrotechnic assembly plants.

In anticipation of the approval of the above recommendations, and realizing the urgent necessity for experienced pyrotechnic operators, the Plant Facilities Section established the Ordnance Pyrotechnic Schools in New York under the direction of Henry B. Faber. Student units were established at the various pyrotechnic factories and extensive research and development was undertaken.

It was not until after this latter date that the Chemical Research Branch of the Trench Warfare Section was established—on October 24, 1918. The lateness of this date will indicate the condition with respect to the scientific treatment of the pyrotechnics problem. At that time it was stated that the most pressing problem for the consideration of the Chemical Research Branch was that of suitable specifications for the chemicals to be employed in the manufacture of military pyrotechnics. It appeared that no work of this character had been previously undertaken by anyone connected with the Ordnance Department and investigation and inquiry soon developed that neither the British, French, nor Italian military authorities had made such study.

Apparently the first logical step was to consult with the manufacturers of pyrotechnics and to use the information thus obtained for the formulation of a tentative draft of specifications to tide over the pressing emergency. It was planned that an extensive chemical investigation should be made with respect to each chemical having a part in the manufacture of pyrotechnic material to ascertain the degree of purity required, the amount of moisture permissible, and the best degree of fineness in grade.

Visits were made to several of the more important plants which were manufacturing pyrotechnic material for the Government and conferences were held with the men best qualified to give information. It was plainly evident that none of the fireworks manufacturers had a real chemical control of their manufacturing processes. At one or two plants some slight attempt was occasionally made to exercise some degree of chemical control, but, inasmuch as none of the manufacturers purchased their chemicals on specifications or appeared to understand the chemistry involved in the functioning of the finished product, such attempts were naturally not fruitful. It was stated by one of the most intelligent men interviewed that he always tested the chemicals by tasting them.

It was the practice of each fireworks manufacturer to buy his chemicals from the same source year after year; his only specification was that the chemical in question "must be the same as that previously furnished." It appears that the manufacturers of the chemicals had learned to know the needs and idiosyncrasies of each of their clients among the fireworks manufacturers and had supplied different grades of material to the different fireworks manufacturers although the chemicals were to be used for the same purpose by each.

The need for chemical control in the manufacture of military pyrotechnics was illustrated by a concrete example: Previous to the war, arsenic disulphide, known in the trade as "red Saxony arsenic" and used for the production of yellow smoke, was imported from Europe. The war resulted in the cutting off of importation and the

use of domestic material became necessary. Trouble at once developed. It was found that to obtain a given volume of smoke, the employment of about 50 per cent more of the chemical was necessary, but why this increase was necessary was not known to the fireworks manufacturers. Trouble of another and very serious nature developed. The workmen using material frequently became badly poisoned. In spite of this, no case had developed in which a chemical analysis was resorted to by the fireworks manufacturers. An Army Ordnance Department chemist made an analysis of the material and found that it contained from 45 to 50 per cent of white arsenic (arsenic trioxide), while the "red Saxony arsenic," formerly employed, and which had been obtained from abroad, was a naturally occurring mineral (realgar), was very pure, and only required grinding to the proper degree of fineness in order to suitably prepare it for its purpose.

The greatest difference of opinion was encountered as regards the permissible quantity of various impurities in the chemicals. Apparently no detailed study of tolerances had been made. It was well known that the presence of small quantities of sodium salts was very harmful in strontium or barium salts, as the yellow produced by the incandescent vapor of metallic sodium degrades other colors: but the actual quantity which was permissible without serious degradation of color was not known. The same may be said regarding the presence of calcium strontium salts or of calcium and strontium in barium salts. The question of the permissible amount of moisture was also one which required more adequate information. All fireworks manufacturers were agreed that moisture should be avoided, and some of them specified that the chemicals furnished them should be dry; yet upon receipt the kegs were opened and allowed to stand open in a humid atmosphere possibly weeks before using. To offset the influence of the atmospheric moisture taken up by the chemicals, it was the practice of the mixer to add other ingredients. At some of the plants the chemicals were kept dry, or were dried before mixing. and the resulting products from these plants were much more uniform in quality.

The moisture content of the chemicals is naturally dependent on the hydroscopicity of the salt itself or of the impurities contained therein. This again brings up the question of allowable impurities For example, a quantity of calcium chloride, which might have no serious effect on the color produced by a strontium salt, might make the mixture so hydroscopic as to render it practically useless. Calcium and magnesium salts, because of their hydroscopic nature, are especially to be avoided and are impurities which are likely to occur in the other salts used. Detailed studies as to the tolerances with respect to these impurities have not been made.

The next question which engaged attention was that of the possibility of substitution or provision for choice of material for use in the manufacture of pyrotechnics with a view to reducing cost and providing against embarassment in the event of a scarcity of some element developed. The highest grade of shellac is costly and if it developed that a lower grade could be used to equal advantage, considerable saving would be effected. The function of shellac is to furnish a suitable binder and control the rate of combustion. The heat produced volatilizes and dissociates the salts which give color to the flame. The shellac employed must necessarily contain no substitutes which would degrade the color of the flame. Some years ago, the Board of Explosives forbade the use of chlorate and shellac mixture in the manufacture of railway fuzes, believing them to be dangerous. This mixture is used together with flame coloring material in position lights, etc., and some of the fireworks manufacturers did not concur in the opinion held by the Board of Explosives. The manufacturers of railway fuzes used mixtures of potassium perchlorate and sulphur in place of chlorate and shellac. Inquiry developed that the immediate substitution of perchlorate would be impossible for a large pyrotechnic program but that the production of perchlorate could be rapidly increased.

But one concern in the United States was manufacturing this material in quantity and practically its whole production was being used by the manufacturers of railway fuzes. While within a few months the production of perchlorate could be increased to provide practically any quantity desired, it was found that extended study should be made first as to the necessity and desirability of the substitution of the perchlorate mixture.

Specifications were compiled and were regarded as being sufficiently rigid for the use of chemicals to be used for military pyrotechnics. Conference with the manufacturers of chemicals led to the belief that the specifications as laid down were reasonable and that no particular difficulty would be encountered in obtaining material of the required purity.

Reference was made to work done by the Chemical Warfare Service at the American University in connection with the signal smokes which had been developed by them and which were believed to be particularly good.

The pyrotechnic schools were disbanded November 30, 1918, but Mr. Faber, with a small corps of assistants, continued the preparation of records of the investigation and work done by engineers and students, and a file of valuable data relating to plant facilities, types of factories, development of and references to formulæ is on file in the Trench Warfare Section for future reference. (File 319.12/17.)

The feeling was expressed that the whole question of military pyrotechnics was one deserving of scientific development. No ex-

tensive research along these lines had been conducted and completed, and the expressed opinion considered the advisability of a Government pyrotechnic laboratory and arsenal to permit of the many problems involved being studied and the solutions embodied in definite drawings and specifications.

A large work of three volumes on pyrotechnic production is now nearing completion.

While the requirements had been very largely increased during August of 1918, a still further increase in these requirements had later been estimated, and the requirement sheets embodying these later increases were about to be issued just as the armistice was signed.

The following table will indicate the requirements in force as of the date of the signing of the armistice and data with reference to the major items of pyrotechnics available then and later:

Principal items in pyrotechnics.

Item.	Total requirements.	Requirements to Nov. 1, 1918.	Ordered in the U. S.	Ordered from abroad.[1]	Floated from U. S.	Completed in U. S. to Nov. 11, 1918.	Total completed in U. S.
Rockets, signal star, Mark I:							
White, 6 stars	1,145,186	363,563				[2] 437,101	
3 stars	1,144,009	362,386					
1 star	1,144,009	362,386					
Red, 6 stars	1,145,186	363,563					
3 stars	1,144,009	362,386					
1 star	1,144,009	362,386					
Green, 6 stars	1,099,588	335,680					
3 stars	1,118,539	354,631					
1 star	1,118,539	354,631					
Rockets, signal parachute, Mark I:							
Red caterpillar	1,368,530	413,854	255,000				5,000
White caterpillar	1,369,707	415,031	255,000				5,000
Green caterpillar	1,368,530	413,854	255,000				5,000
Red	386,506	159,326	106,024				109,159
Green	401,006	173,826	117,904		2,800		120,535
Yellow smoke	1,135,115	361,132	63,000		53,700		96,539
White illuminating	2,689,293	822,060	159,000		2,000		188,522
Flag	610,923	194,803	45,000				6,461
Amber			5,750				5,760
Rockets, signal, old style:							
Yellow smoke			36,100				36,100
Red			71,976		32,200		71,976
Green			60,096		57,175		60,096
Amber			35,697		} 31,000		{ 36,062
Golden rain, Mark I			1,553				{ 1,553
Cartridges, VB star, Mark I:							
White, 6 stars	1,638,572	483,832	95,000			[3] 110,000	101,120
3 stars	1,641,900	484,798	95,000				95,174
1 star	2,437,292	715,672	145,000				145,000
Red, 6 stars	673,452	203,692	40,150				40,150
3 stars	720,044	217,216	40,000				40,000
1 star	1,562,028	461,514	90,000				90,270
Green, 6 stars	673,452	203,692	40,000				40,000
3 stars	673,452	203,692	40,000				40,000
1 star	317,356	100,330	20,000				20,408
Cartridges, VB parachute, Mark I:							
White	3,573,320	1,043,520	200,000				205,117
Red	2,867,784	838,728	165,000				167,508
Green	2,867,784	838,728	165,000				165,210
White caterpillar	582,208	183,932					
Red caterpillar	488,264	148,048	30,000				30,000
Green caterpillar	488,264	148,048	30,000				30,234
Yellow smoke	405,064	123,888	20,000				0

[1] Impossible to determine quantity ordered and delivered until details of final settlement are received.
[2] Includes all types of rockets.
[3] Includes all types of VB cartridges.

Principal items in pyrotechnics—Continued.

Item.	Total requirements.	Requirements to Nov. 1, 1918.	Ordered in the U. S.	Ordered from abroad.	Floated from U. S.	Completed in U. S. to Nov. 11, 1918.	Total completed in U. S.
Cartridges, Very parachute 25 mm.:							
White	1,969,246	695,192					
Red	1,509,594	464,755					
Green	1,509,594	464,755					
White caterpillar	3,481,434	1,037,110					
Red caterpillar	3,959,002	1,175,731					
Green caterpillar	3,959,002	1,175,731					
Yellow smoke	2,682,714	805,270					
Cartridges, Very star, 25 mm.:							
White, 1 star	6,781,497	1,955,272	100,000				0
Red, 1 star	1,884,345	573,802	100,000				0
Green, 1 star	1,884,345	573,802	100,000				0
Red, 6 stars	3,327,033	992,564					
3 stars	3,327,033	992,564					
Green, 6 stars	3,327,033	992,564					
3 stars	3,327,033	992,564					
Wing tip flares, Mark I:							
White	497,450	486,400	56,082		20,000	} 70,000	{ 47,882
Red	497,450	486,400	56,082		13,000		41,283
Airplane flare, Mark I	83,228	76,092	65,083			2,100	8,000
Position lights, Mark I (ground):							
White	2,883,123	892,251	305,000		10,798		150,002
Red	2,315,779	754,791	575,000		49,823	[1] 1,187,532	482,017
Green	2,315,779	754,791	380,000		19,856		275,417
Position lights, Mark II (hand), white	2,981,823	990,951	863,000		481,827		813,034
Smoke torch, Mark I	3,328,000	966,000	500,000			31,000	188,102
Rifle lights, Mark I, old style, white			320,000			55,000	55,000
Signal lights, Mark I, old style:							
White			29,000				0
Red			143,000				55,000
Green			143,000				55,000
Signal lights, Mark II, for Mark III pistols:							
White			1,000,000			[2] 2,661,008	994,360
Red			1,000,000				884,780
Green			1,000,000				720,348
Signal pistols:							
Mark III, 10-gauge			20,460				20,460
Mark I, 35-mm			29,669				1
Mark IV, 25-mm	194,680	97,016	166,719				25,066

[1] Includes all types of position lights.
[2] Includes all types of signal lights.

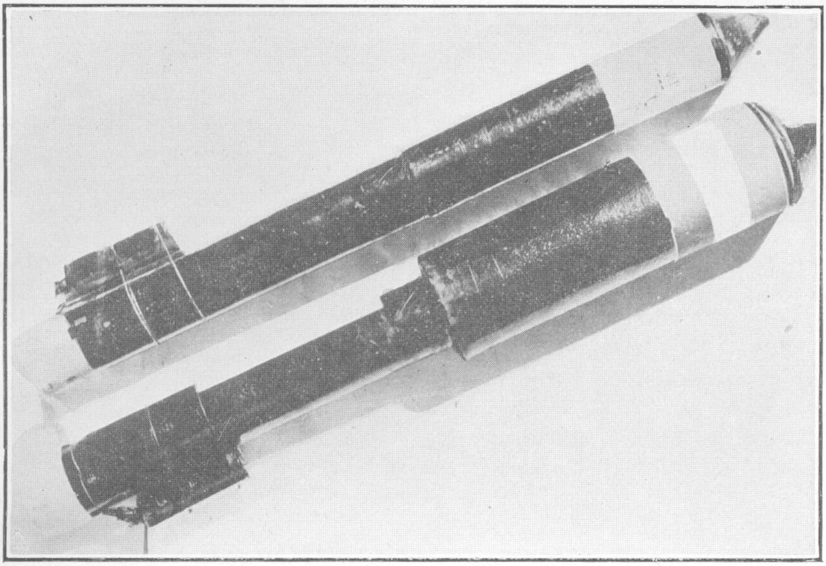
NOTE.—Columns relating to completions and flotations may be considered more or less as of armistice date, as cancellations became effective shortly thereafter.

COURSE OF DEVELOPMENT AND MANUFACTURE.

In the improvement of the rockets which were used by the Signal Corps, signal rockets Mark I and Mark II were developed and proved to possess 95 per cent efficiency in functioning and performance. This marked a distinct improvement over the rockets previously employed, and the new rockets also attained a height of 800 to 1,200 feet as compared with a height of 200 to 400 feet with the old rockets. The new rockets burned approximately one minute. Under Mark I were included the red and green rockets, and in addition a rocket known as the "golden rain" type, which had been substituted for the white rocket previously employed. This golden rain type in turn gave way to a rocket with an amber star.

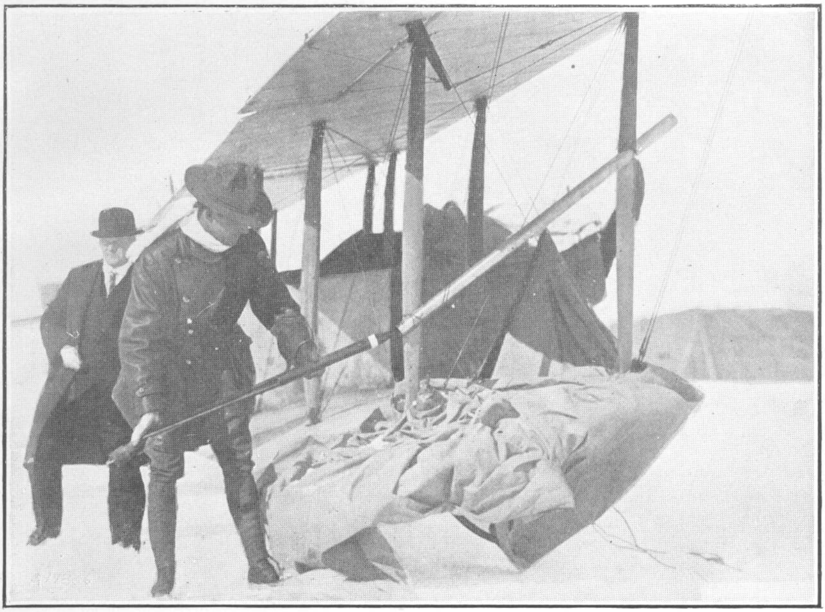
Later direction from France, however, led to the abandoning of this type in favor once more of a white rocket to be used for illuminating

PLATE 1a.



FLAG AND SIGNAL ROCKETS. TRENCH WARFARE SECTION, ORDNANCE DEPARTMENT, TOURS, FRANCE.

PLATE 2a.



TESTING INCENDIARY ROCKET AT MILITARY AVIATION FIELD, MINEOLA, L. I., NEW YORK, 1917.

as well as for signaling. Originally the day rocket using yellow smoke was designated "Signal Rocket Mark II."

The above references to efficiency and height attained, which are gathered from an Ordnance Department record, were doubtless based upon tests made under favorable conditions, for another Trench Warfare Division report confines the heights reached to 650 or 800 feet, and in conversation with a Signal Corps officer, who had been in France with the First Division, he called attention to the fact that 1,200 feet would be over twice as high as the Washington Monument; that he had seen rockets in service at the front, both of French make and of American make, that certainly none of them had reached the maximum height stated, and that his impression was that none of them had reached half that height. Regarding the matter of efficiency, he called attention to the catalytic action of certain chemicals employed in pyrotechnics, which caused deterioration. When questioned concerning the change from the golden rain type of rocket to the amber star, in the face of the general contention that it was more reliable to adhere to form rather than color in differentiation between signals, he stated that the change was probably made after it had been found that disintegration due to catalytic action within the rocket would cause a change in the form of the burst. Apart from yellow smoke, which was used mainly by headquarters, red, white, and green were the only colors employed.

In connection with rockets, position lights, and smoke torches, an ignition disk is provided with each piece, and on tearing off the protective band this ignition disk is made available to be rubbed by hand on a friction quick match, attached to the fuze, to cause the piece to function.

The VB signal cartridge was fired from a rifle grenade discharger attached to an infantry rifle. A .30 caliber blank cartridge was, however, used in the rifle, and this cartridge was taped onto each VB signal cartridge and detached at the time of use. The cartridges were marked for ready identification either by day or by night. At the beginning of our operations in France the organizations which used the VB signal cartridge encountered difficulty in its operation due to the fact that the blank rifle cartridge attached to the VB signal cartridge of French manufacture was the 8-millimeter cartridge, which did not fit the American rifle; hence it was necessary either to use French rifles or to extract the bullet from the American caliber .30 service cartridge before the signals could be used. The marking of the cartridges was in French and this caused trouble in identifying the different signals. Many misfires occurred due to the percussion cap in the French VB signal cartridge not being placed central with the firing pin, or placed too far away to be struck by the the firing pin inside of the signal cartridge, and in many cases when

164404—20——3

the cartridge did function, the parachute would fail to open. According to an Ordnance Engineering Division report received from overseas, there was a difference of opinion as to the desirable height of flight of this type of signal. On misty nights the signal would function above the mist and could not be seen, and in hilly terrain the signal would not function high enough to be seen on clear nights. To remedy this difficulty a blank cartridge with a heavy charge and a separate blank cartridge with a light charge could be developed. Contrary to reasoning with reference to the rockets, concerning the necessity for determining their source, it was specified that this VB signal must leave no trail of sparks, as such trail would aid the enemy in locating the position of the man who fired it. Experimental samples of the American manufactured VB cartridges, with blank cartridges attached, were received in France a few weeks before the armistice was signed, and in these the percussion cap of the signal cartridge was exploded by the pressure of the gases from the discharge of the rifle cartridge instead of by a firing pin as is used in the French type.

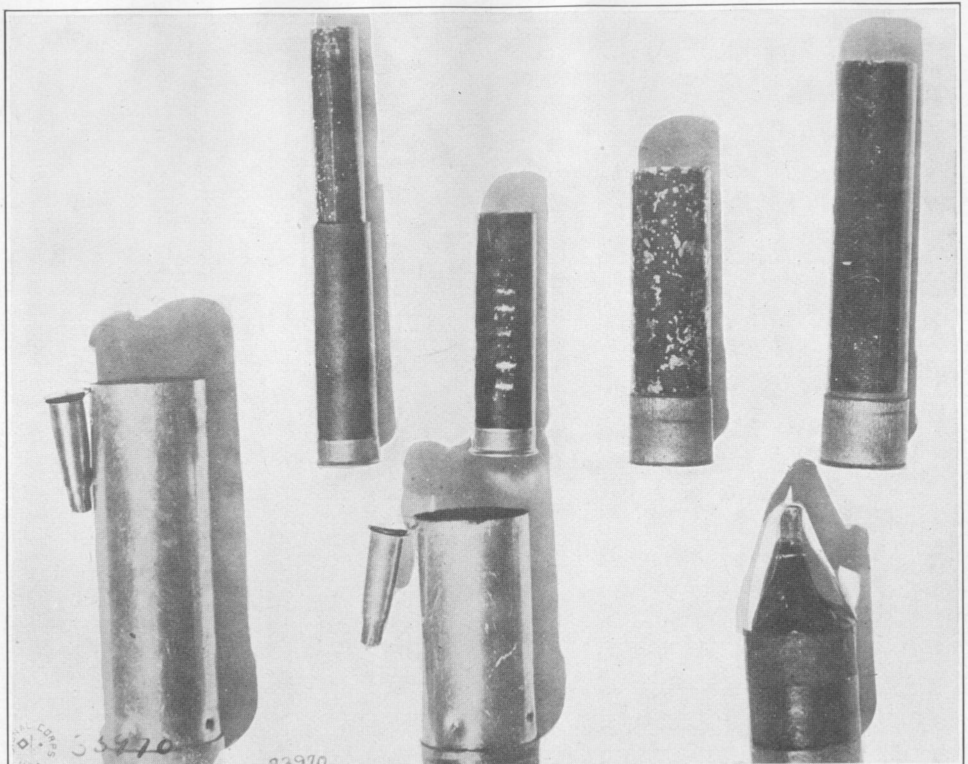
Signal light Mark I was designed to be used in conjunction with the VB discharger and the Army rifle for signaling purposes by the Infantry. The light functioned satisfactorily but the American Expeditionary Forces would not accept the device, as there was a trail of sparks from the signal when it was fired. As these signals were used only at night this would enable the enemy to locate the man firing the signal. The VB discharger Mark I, developed from the French design, was therefore adopted instead of the rifle light, as the VB cartridge signal did not leave a trail of fire.

The rifle light Mark I is a development from the Frankford Arsenal rifle grenade, illuminating, and was designed to be thrown from a VB rifle discharger. It contains an illuminating pellet, suspended by a parachute and burning 20 seconds with from 40,000 to 60,000 candlepower. The parachute was of such size as to suspend the illuminant at practically the point of burst until consumed and the cost of the new cartridge was less than one-fourth that of the Frankford Arsenal type.

This is a matter of nomenclature of a development of about November, 1917, on the same work order with signal light Mark I. The specimen retained of the signal light was produced by the Nixon Fulgent Products Co. and that of the rifle light by the Unexcelled Manufacturing Co.

CARTRIDGES FOR 25-MILLIMETER VERY PISTOL (PYROTECHNICS).

These cartridges were used in conjunction with the 25-mm. Very pistol Mark IV for signaling purposes by troops. Sixteen types of these cartridges were authorized, including signals both with and with-



TYPES OF SIGNAL CARTRIDGES 25 MM. AND 35 MM.

In the upper type the propelling charge is a part of the cartridge. In the lower type the propelling charge is separately contained. In the lower right of the photo is a signal light. Trench Warfare Section, Ordnance Department, Tours, France.

out parachute. Orders were placed in the United States for 300,000 of the cartridges, but at such a late date that none were produced. The cartridge case of the 25-mm. cartridge not being of the standard American size none of the shotgun cartridge manufacturers desired to produce the paper-cartridge case. Contracts were therefore awarded for metal cartridge cases and apparently these were entirely satisfactory. It was in cablegram 1005-6A of April 27, 1918, that we were advised by the American Expeditionary Forces that the No. 10 gauge size of signal cartridge appeared to be too small for signal work, and it was their belief that it would be necessary for us to develop the 25-mm. or 1-inch size.

SIGNAL LIGHT MARK II (VERY).

In connection with the Very pistol cartridge, which had been issued by the Navy to the Signal Corps, the composition was not considered stable by the Army Ordnance Department nor was the degree of visibility considered satisfactory and hence new specifications were provided by the Ordnance Department. This new cartridge was known as "Signal Light Mark II." This signal was used by the Navy before the present war and adopted by the Army. Total weight approximately 1 ounce. Used in conjunction with Very signal pistol model Mark III by the Infantry. Contracts were awarded and large quantities made but the signals were abandoned on instructions from the American Expeditionary Forces, as it was decided that our signal cartridges should be the same size as the French so that signals could be interchangeable between troops.

CARTRIDGE FOR 35-MILLIMETER SIGNAL PISTOL (PYROTECHNICS).

This cartridge was used for signaling purposes in aviation in conjunction with the 35-millimeter signal pistol (aviation). Twenty different types of 35-millimeter cartridges were authorized in the pyrotechnics program but no contracts were awarded, as before the production was started in the United States the caliber was changed to 25 millimeters. In general it may be said that the cartridges for use in the same pistol, while of the same caliber, were not all of the same length; in fact, the ends of some of the cartridges would extend far beyond the muzzle of the pistol. The difference in length was due to the quantity of pyrotechnic material which was called for by the type of signal for which the cartridge was used; that is, the length of the caterpillar or the number of stars. For aviation work it was not necessary to have any considerable amount of propelling charge in the cartridge, as the altitude was provided for by the plane being in the air, and it was only necessary to propel the signal a

short distance clear of the plane. For Very pistol cartridges to be used from the ground, however, a stronger propelling charge was necessary in order to provide for the functioning of the signal at the proper altitude.

In a letter dated September 19, 1919, from the Engineering Division of the American Expeditionary Forces regarding these cartridges, the point is brought out that at that time the French were using a signal burning first in one color and then changing to another color and that the adoption of this changing type was not known to the American Expeditionary Forces until it was actually in service. The thought expressed by the American Expeditionary Forces was that there was a chance that one of the colors might not function and that thus the proper signal would not appear and a serious misunderstanding might result. This brings to mind the reference to the uncertainty in the operation of some of the military pyrotechnics through catalytic action, and possibly through dampness, as referred to in a previous part of this chapter.

VERY SIGNAL PISTOL, MARK III.

This pistol was used by the Navy prior to the present war, and was adopted by the Army. It was used by the Infantry in conjunction with the signal light Mark II (Very). A contract was awarded to the Remington Arms Co., Bridgeport, Conn., for the manufacture of a quantity of these pistols but on receipt of word from the American Expeditionary Forces that the signal cartridges should be of the same size as the French, the contract for these pistols was canceled, and the 25-millimeter Very pistol, Mark IV, was adopted to supersede it. Some of the No. 10 gauge Mark III pistols had been shipped abroad but were returned to this country and were used for training purposes.

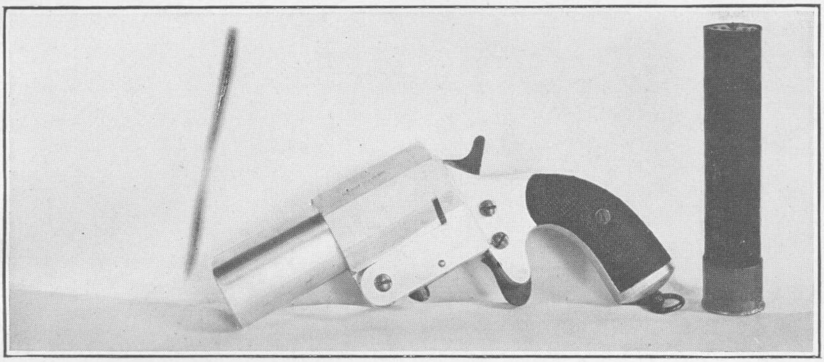
25-MILLIMETER VERY PISTOL, MARK IV.

This pistol was used by our Infantry for signaling purposes. There were no particular difficulties encountered in production and the number ordered and produced are indicated in the table dealing with production.

25-MILLIMETER VERY PISTOL, FRENCH MODEL 1917.

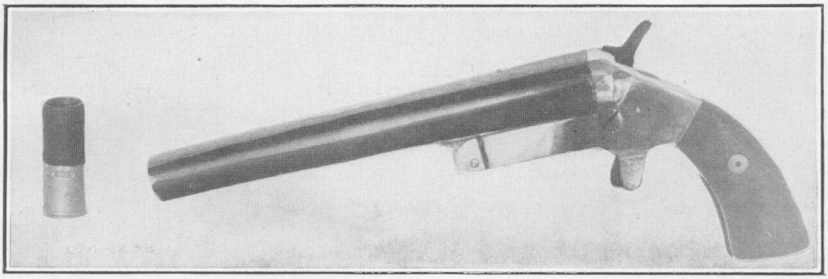
This pistol was used for signal work and is the latest type designed by the French. In Weekly Letter of September 7, 1918, from the Ordnance Department at Washington to the American Expeditionary Forces, attention was called to a pamphlet which had been received from France regarding this model and particularly to the radically different grip, the longer barrel of steel instead of brass, and other minor changes as compared with the 25-millimeter Very pistol, Mark IV, then in production. The thought was advanced that possibly

PLATE 4a.



VERY SIGNAL PISTOL, WITH CARTRIDGE. FOR USE FROM AIRPLANE FOR COLORED FLASH SIGNALS, ETC.

PLATE 5a.



VERY PISTOL AND CARTRIDGE.

the powerful recoil of the pistol made necessary a different construction and a different grip and that a greater range was desired, thus accounting for the length of the barrel. It was requested that a definite statement be made whether or not it was desired to put the new French model into production, and reply of October 3 stated that the new French model had not been tested and that they were not in a position to state that it was superior to the one which was already in production in the United States. They recommended, however, that tests be made here, and if the new model proved superior to a marked degree that it be put into production as soon as existing contracts on the older design were completed. In both of these letters the new design was referred to as that of 1918. Tests were made and the opinion was expressed that it was not as satisfactory a pistol as the Mark IV, as the locking mechanism worked too hard and the trigger-pull was too great. No production was started.

35-MILLIMETER SIGNAL PISTOL, MARK I (AVIATION).

This pistol was used by aviators to fire signal cartridges. Contracts for 29,669 were awarded to the Dohler Die Casting Co., Brooklyn, N. Y., the Hammond Typewriter Co., New York City, and the Parker Bros. Gun Co., Meriden, Conn. One pistol was produced. Prior to the introduction of this pistol, we had no pistol for aviation work and adopted the French design. The American design was satisfactory except for the firing pin and firing-pin spring. In connection with this a different type of hammer is desirable to eliminate the necessity for placing the hammer at half cock in order to load the pistol.

35-MILLIMETER SIGNAL PISTOL, MARK II (AVIATION).

This pistol is the same as the 35-millimeter signal pistol, Mark I (aviation), except that the French design is followed more closely in detail. It was proposed to use the above title to identify the new drawings which would be used in the manufacture of sand-cast aluminum parts instead of die cast, as had been used in the 35-millimeter signal pistol, Mark I. The die-cast pistol proved successful, so this project was abandoned.

35-MILLIMETER SIGNAL PISTOL (BRASS).

Five sample pistols of French design were received from abroad. This pistol was designed by the French to take the place of the 35-millimeter signal pistol, Mark I, but information was received to the effect that no improvement was apparent, and an experimental order placed in the United States for the manufacture of 20 of the brass pistols was canceled.

35-MILLIMETER SIGNAL PISTOL, MARK III (AVIATION).

This project was authorized under this nomenclature for the copy of a new French model, but word being received from abroad that certain defects in the 35-millimeter signal pistol, Mark I, had been eliminated, it was the opinion that the Mark I pistol was a better design than the Mark III, and hence no further action was taken in this project.

POSITION LIGHT, MARK I, WHITE, RED, AND GREEN (GROUND).

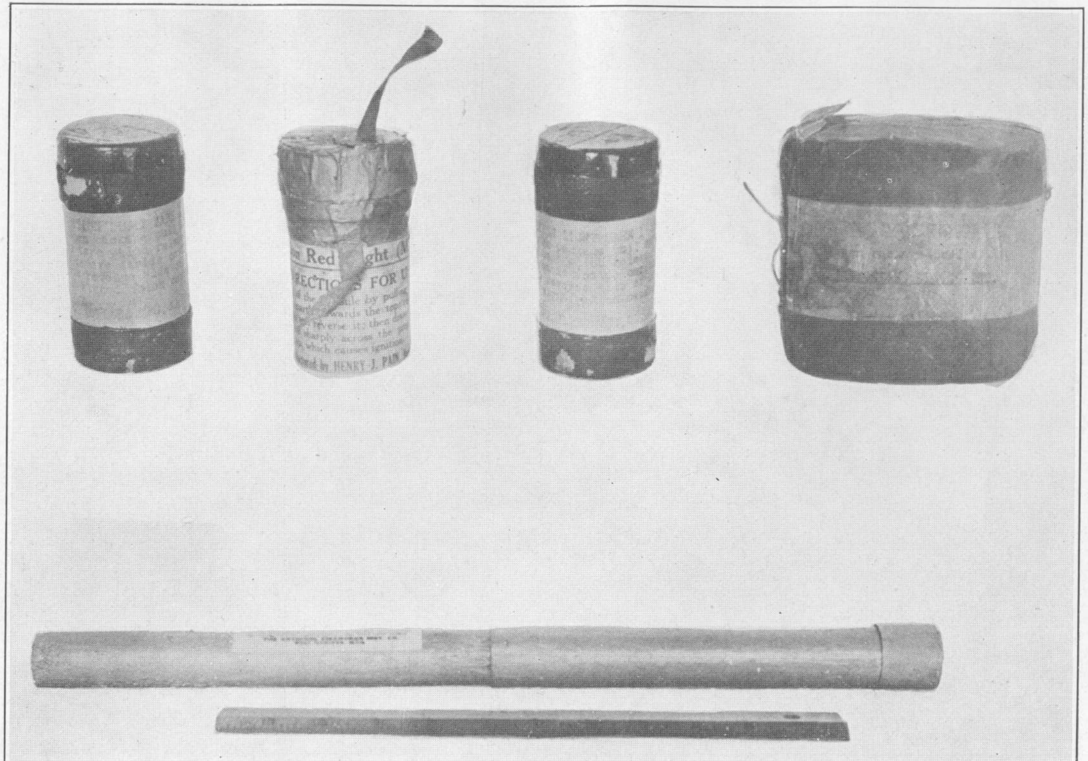
Steps were taken to develop a ground position light, but during the experimental stage a modified form of the British ground flare was adopted. The device, which was later independently perfected by the Ordnance Department, is known as "Position light, Mark I, ground." There are three types—white, red, and green. Each type burns about a minute. The white is of about 5,000 candle power; the red, about 1,400, and the green, about 1,200. These are regarded as superior to any other known pyrotechnic devices of the kind.

This is a development of the position light of the Engineering Corps and of the British ground flare. It weighs from $4\frac{1}{4}$ to $5\frac{1}{4}$ ounces, varying with the color. Its use is in conjunction with troop movements. It is provided with a friction igniter and when ignited is placed or thrown upon the ground. As in the case of the hand position lights, they were also used at times by airplane squadrons for marking the landing field at night.

Smoke torch, type "S," adopted by our forces was used both as a signal and for producing a smoke screen. It is of British manufacture and was not manufactured in the United States. It burns for approximately five minutes, giving a dense yellow smoke. The smoke composition is packed in a metal case approximately $3\frac{3}{4}$ inches in diameter, and about 6 inches long, and is ignited by a friction striker. The size and weight were carefully considered in the design of this torch, due to the fact that it was necessary for the soldier to carry it. Samples of two types were sent to the United States and both were considered satisfactory by our troops.

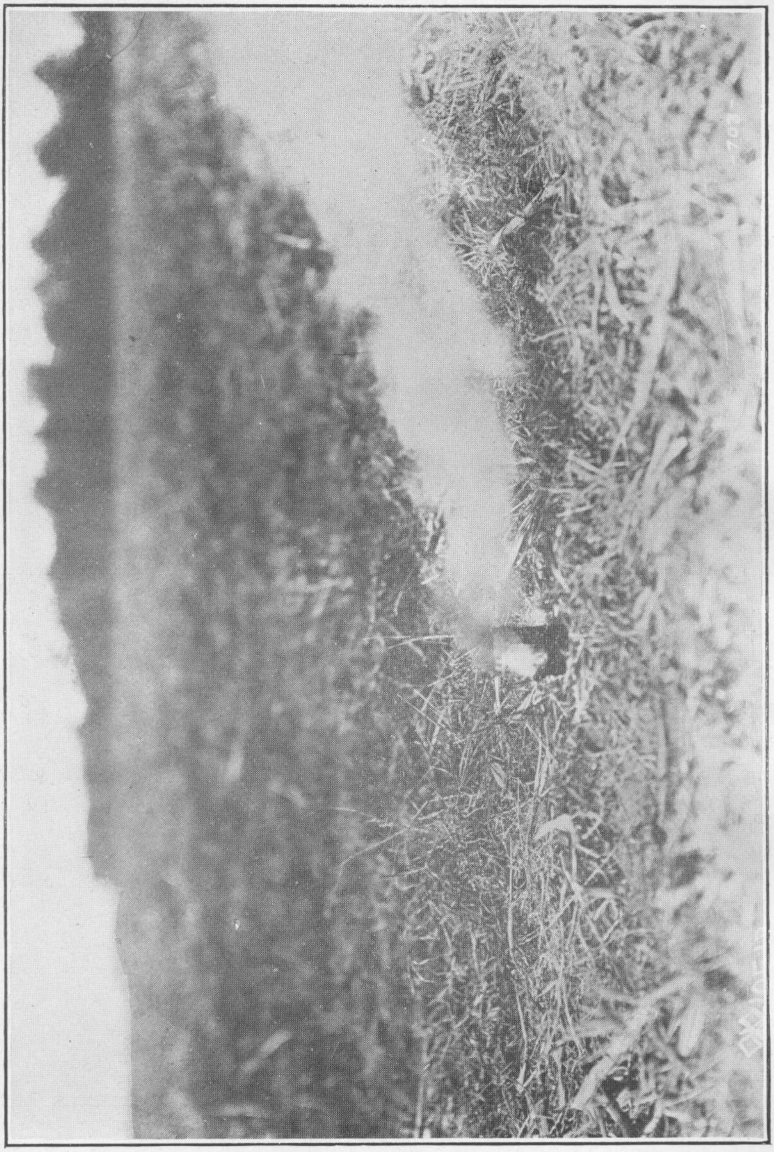
SMOKE TORCH, MARK I.

Of the types of pyrotechnics, which were more or less developed in our service at the outbreak of the war, the American smoke torch was arranged like the British type, which had been followed, to burn from $2\frac{1}{2}$ to 3 minutes. It gave out, however, a considerably larger volume of smoke as compared with the samples received here, and, later, on cable advice from the American Expeditionary Forces, the burning time was increased to 4 minutes, and the design and chemical



TYPES OF ORDNANCE SIGNAL LIGHTS. POSITION LIGHT MARK I (ABOVE). POSITION LIGHT MARK II.

PLATE 7a.



SMOKE TORCH.

UNCLASSIFIED

formula adopted resulted in smoke torch, Mark I. The smoke torch, Mark I was manufactured in the United States and was in quantity production when the armistice was signed.

Holt wing tip flares, which were used by our air squadron, were of British manufacture. The flare is ignited by means of an electric squib imbedded in the upper end of the flare and connected to a switch in the fuselage of the plane. Two types of these flares were used; one giving a red mist-penetrating tinge, and the other a white light. Much difficulty was encountered in the use of these flares through the failure of the electric squib to function. Instead of using two to a plane to insure illumination for night landing, the aviators were using six and eight to a plane.

The American adaption, known as the *wing tip flare, Mark I,* was also made with the white light and with the red tinge, and while laboratory results of 22,000 to 25,000 candlepower were obtained, difficulty encountered in connection with the quality of the chemicals obtainable at the time resulted in production requirements being reduced to a minimum of 12,000 candlepower for the white flare and a minimum of 6,000 candlepower for the red tinge flare. The burning time was 1 minute.

Airplane flare, Mark I, modeled after the Michelin illuminating bomb, was designed for use in aviation work to illuminate the country which the aviator desired to bomb and also occasionally for landing purposes. It consists of a thin sheet-metal cylinder, about 4 feet long and 4 inches in diameter, provided with guiding fins at the tail of the cylinder a small metal revolving vane at the nose, and two projecting buttons for providing means for attachment to a releasing device for providing means for attachment to a releasing device located underneath the wings of the plane. The cylinder contains an igniting device, an expelling charge, an inner case containing the illuminating compound, and a silk parachute connected by cords to the inner case. The mounting of the vaned wheel consists of a brass stud or shaft passing through the nose carrying on its inner end the ignition striker. This stud or shaft, instead of having a smooth bearing through the nose piece, is threaded for a portion of its length, and is likewise provided with a flat surface, and a cotter pin hole at that part of the shaft which is exterior to the nose piece.

During shipment and handling a cotter pin passing through the hole in the shaft prevents the firing pin striking the ignition surface. On being mounted on the plane the cotter pin is removed and the flare is attached by means of the attachment buttons provided to a releasing device on the lower side of the wing, and, in so attaching, the flat surface on the shaft of the vaned wheel is inserted in a clip which prevents the shaft from turning. At such time as the aviator desires to release the flare, he operates from the fuselage the mechanical connection to

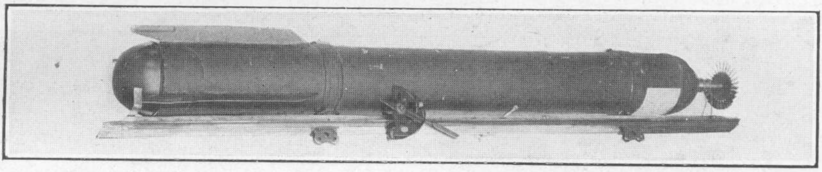
the releasing device, and the cylinder then drops free from the plane and the vaned wheel commences to turn as a result of the action of the impinging of the air against it, as would be the case with a windmill or pinwheel. In so revolving, the shaft advances on the thread in its bearing until its roughened inner end is forced into friction contact with the quick match which ignites the expulsion charge. Ordinarily this occurs when the flare casing has dropped about 200 or 300 feet below the plane. On the ignition of the expulsion charge, the inner case, together with the parachute, is expelled from the outer case at the guiding vane end of the cylinder and the illuminating charge in the inner case is ignited. The parachute opens and the burning illuminant is thus suspended and permitted to slowly descend toward the earth.

The above is a description of the manner in which the flare is designed to function. Its total weight is about 36 pounds. It is the best flare of this character that has thus far been developed, but it is not an entirely satisfactory device. Its successful functioning is dependent upon a train of action and the failure of any part to function affects the successful operation. It is felt that the entire firing mechanism should be changed to insure more positive action of the firing pin. A clockwork time mechanism has been developed and will probably receive further consideration. Some difficulty has been experienced in the ignition of the illuminant due to the first fire breaking away from the illuminant when the parachute has opened. It is felt that some parachute failures are bound to occur, due either to the parachute not opening properly or to the breaking of the suspension cords. In the present device no means is provided for an adjustable fuze.

The airplane flare of American design was designed to burn about 7 minutes with from 225,000 to 350,000 candlepower, as compared with a burning time of 6 minutes and 55 seconds and a candlepower of 190,000 in the French Michelin type.

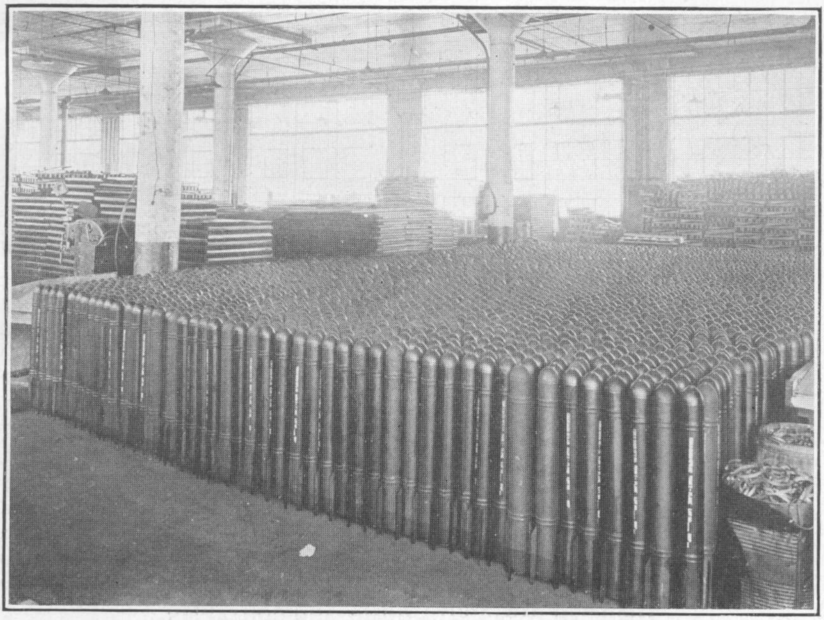
The airplane flare Mark II is an adaptation of the French Bourges illuminating flare and is used in conjunction with night observation from airplanes. It was designed to be thrown from the airplane by the pilot or the observer and is employed in an emergency and as an auxiliary to airplane flare Mark I. The French flare is cylindrical in shape, with a length of 20 inches and a diameter of 2¾ inches. The illuminant is suspended by a cloth parachute which is from 3 to 4 feet in diameter. A time fuze is provided which can be set to the number of seconds desired by the aviator. In operation the flare is dropped from the airplane by the aviator or observer and is caused to function by pulling a small string attached to the firing mechanism. The experimental work was carried on by the pyrotechnic laboratory of the Ordnance Department, and it did not go beyond the experimental

PLATE 8a.



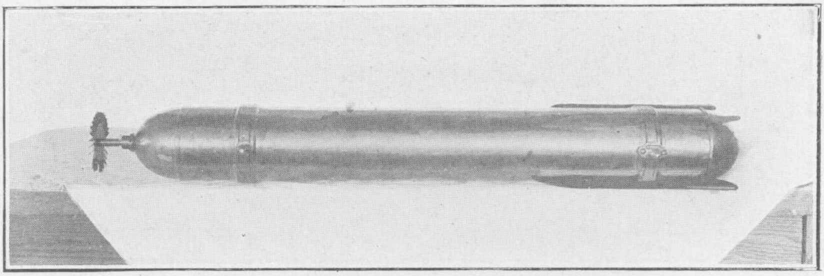
AIRPLANE FLARE MARK I.

PLATE 9a.



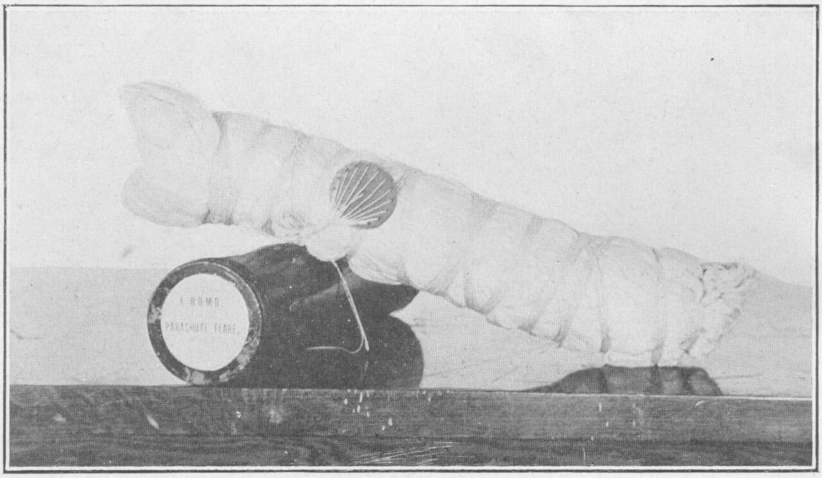
ONE DAY'S OUTPUT OF FLARE BOMBS FOR THE SIGNAL CORPS.

PLATE 10a.



MICHELIN PARACHUTE FLARE..

PLATE 11a.



MICHELIN PARACHUTE, BOMB, AND CONTAINER.

stage. Apart from the tests for candlepower, the experimental work was confined to different forms of firing mechanisms, along the lines of standard ignition, the grenade type of ignition, and clockwork and friction types of ignition. The illuminating composition made up at the pyrotechnic laboratory had a burning time of 3 minutes and developed a candlepower of 110,000.

In the French manufacture this Bourges flare is considerably smaller than the Michelin flare from which with wing tip flare, Mark I, was adapted, and has a time fuze which arms it to function much nearer the ground and it is in much greater favor with the aviators than the Michelin flare. A dozen Bourges flares can be carried in the fuselage of the plane while only 2 or 3 Michelin flares can be carried, and these must be suspended from the Michelin releasing mechanism underneath the wings or the fuselage. The Bourges flare is fired by the aviator jerking a cord at the instant he throws the flare clear of the plane. This cord releases the firing pin which is under compression. The firing pin strikes a cap which ignites a time fuze. The objectionable feature of this flare is that the fuze is always armed and recommendation was made that safer firing mechanism be developed. It was suggested that the Bourges flare with a yellow or mist-penetrating light be developed, as this would greatly aid night flying in the zone in which the squadron was operating. The timing arrangement of the fuze should have a greater range. Drawings, specifications, and samples were sent to the United States with a request that they be put into production immediately.

SMOKE MESSAGE TUBE (AIRPLANE).

The message cartridge for the 35-millimeter pistol (aviation) was to some extent used for sending information such as reconnaissance reports, maps, etc., from the airplane to the land force. This cartridge did not have sufficient capacity to meet the requirements of our air squadron. The aviators improvised a type of message tube consisting of a tin can with a cloth streamer, and this worked out satisfactorily with the exception that it did not have a smoke tracer. The idea of the smoke tracer is to aid the watcher on the ground in locating the message after it has reached the ground, and its smoke must be of such color that it can be distinguished from the smoke of bombs or shell. To attract attention before dropping the message, the aviator would blow a whistle or a horn, or in some cases, would fire a few shots from his machine gun in order to attract attention to the message which was about to be released. Tentative drawings were prepared by the Engineering Division of the American Expeditionary Forces of a smoke message tube having a message-carrying capacity 8 inches long by 2 inches in diameter and providing for the ignition of the smoke composition which was located in a compartment in one

end of the tube by means of a Mark II offensive hand grenade bouchon without the detonator.

Work was also being carried on in the United States in the development of a smoke message tube when the armistice was signed.

OFFENSIVE GRENADE FLARE.

The object of this grenade was to replace the Very signals used in aviation, it being much simpler and easier to throw one of these grenades from the plane than to load and fire a pistol. It was developed at the Ordnance pyrotechnic laboratory and the tests conducted with experimental grenades indicated that they could be manufactured to function equally as well as the Very cartridges. The unsatisfactory feature lies in the fact that the star may be blown back onto the plane, as the direction in which the star is expelled can not be controlled. The matter was in an experimental stage at the time of the armistice.

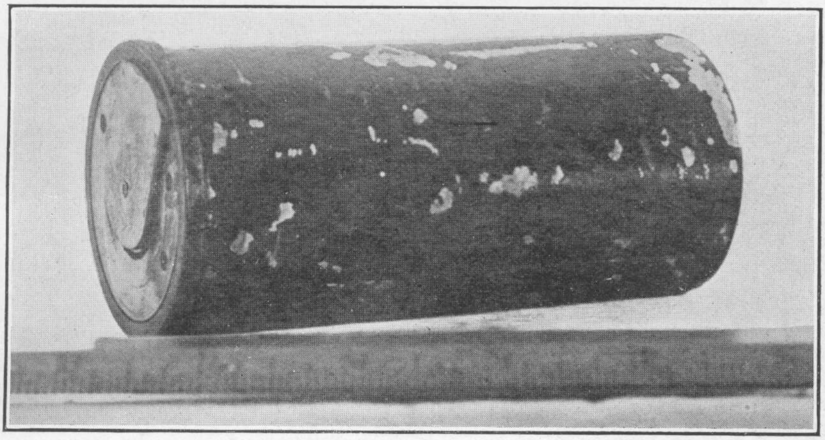
ILLUMINATING BOMB AND GUN, MARK I.

This was an experimental project to provide an illuminating shell of greater range than the rocket. The shell was loaded with a single illuminating star and a 36-inch parachute. The illuminating composition was designed to burn about 20 seconds, giving a candlepower of 60,000 or more. The shell was to burst about 350 feet from the ground and the fuze to give a maximum range of 1,500 feet. The project was not carried beyond the experimental stage, and it was decided to use the Stokes' mortar and modify the Stokes' shell for illuminating purposes.

DROPPING DEVICE FOR INCENDIARY DARTS.

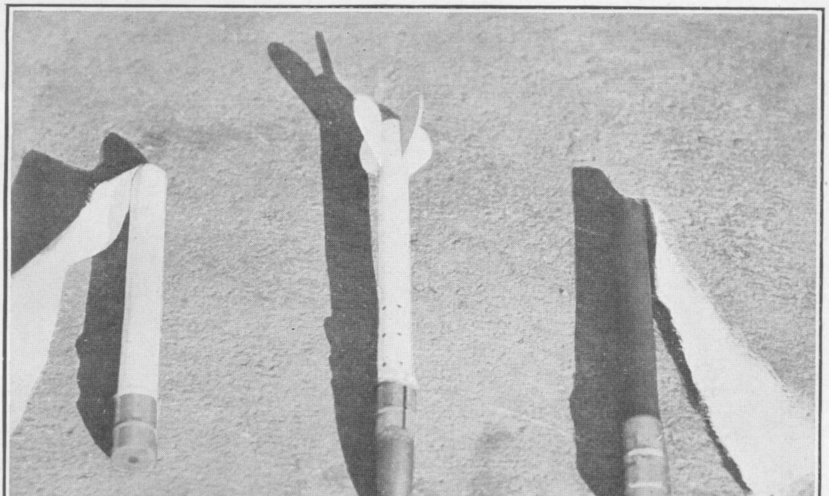
The purpose of this device was to provide a means for the carrying of incendiary darts by airplanes and the dropping of them upon objects which could be set on fire. The project was in the experimental stage at the signing of the armistice. The device was designed to be attached to the standard bomb-carrying device of D. H.–4 airplanes, using the standard release mechanism. A safety device was incorporated in the loading bucket and precluded the possibility of the darts becoming ignited while in the dropping device. The device is pivoted on trunnions at one end, and when released swings about these trunnions in a vertical downward arc, which is retarded slightly at the point when the dropping bucket is pointing directly downward, thus allowing the darts to be spilled. The retardation is then relieved and the remaining momentum of the device, together with the wind pressure due to the movement of the airplane, completes the movement and the empty bucket swings up under the wing of the airplane, where it is caught and held by suitable latches. The value of the device has not yet been demonstrated.

PLATE 12a.



ILLUMINATING BOMB, MARK I.

PLATE 13a.



INCENDIARY DROP DARTS, AIRPLANE TYPE.

The darts to be carried by this device were the incendiary darts, Mark I; the bucket being loaded with 61 darts. The assembled weight loaded was approximately 60 pounds, of which weight 25 pounds represented the weight of the darts.

The incendiary dart, Mark I, was between 11 and 12 inches in length and about 1 inch in diameter. It consisted of a tube containing an incendiary mixture, a nose with striker and cap to ignite the mixture on impact with the ground, and a stabilizer to insure the dart traveling nose downward when released from a plane. In the experiments a cloth stabilizer was at first employed and later a vaned paper stabilizer was used. The basic idea was to provide a dart which on striking the ground would send a radial shower of flame several feet high for the purpose of igniting grain fields or other readily ignitable objectives.

The Mark I incendiary dart was constructed to permit the carrying of large quantities of darts in an airplane, it being considered that as many as 1,000 darts might be carried at one time in a large plane and that it would be possible to scatter the incendiary units over a considerable area. A quantity of darts were sent to France but they were condemned there as not being suitable for the purpose. Those are doubtless fully reported upon by the Chemical Warfare Service.

At the time that the United States was ready to initiate its manufacturing program, only three or four plants were available for quantity production; one of the manufacturing companies having just been organized.

The tabulation immediately preceding will in general indicate the quantity orders placed, and for the presentation of contract details the "History of Production of Pyrotechnics," prepared by the Trench Warfare Division of the Army Ordnance Department and submitted on January 3, 1919, is reproduced.

CHAPTER II.

HISTORY OF THE PRODUCTION OF PYROTECHNICS.

SIGNAL ROCKETS.

JANUARY 3, 1919.

The first contract was let to Unexcelled Manufacturing Co., New York, on December 1, 1917. Quantity production started in January. On May 13, 1918, the Engineering Division changed specifications to conform to French types. This radical change made it necessary for manufacturers to alter their plans considerably. Production of old style signal rockets was as follows:

Article and firm.	Contract No.	Date.	Contracted for.	Completed.
Mark II. Yellow smoke:				
Unexcelled Manufacturing Co	G1121-424TW	Nov. 30, 1917	20,000	20,000
Henry J. Paine	G1191-440TW	Nov. 27, 1917	10,000	10,000
Unexcelled Manufacturing Co	P3274-1128TW	Feb. 22, 1918	6,000	6,000
Henry J. Paine	P3574-1236TW	Mar. 1, 1918	100	100
Total			36,100	36,100
Mark I. Golden rain:				
Unexcelled Manufacturing Co	G1121-424TW	Nov. 30, 1917	1,188	1,188
Henry J. Paine	G1193-442TW	Nov. 27, 1918	365	365
Total			1,553	1,553
Mark I. Amber:				
Unexcelled Manufacturing Co	G1121-424TW	Nov. 30, 1917	8,812	8,812
Henry J. Paine	G1193-442TW	Nov. 27, 1917	9,635	10,000
Unexcelled Manufacturing Co	P3273-1127TW	Feb. 22, 1918	17,250	17,250
Total			35,697	36,062
Mark I. Red:				
Unexcelled Manufacturing Co	G1121-424TW	Nov. 30, 1917	20,000	20,000
National Fireworks Co	G1190-439TW	Nov. 27, 1917	7,500	7,500
Henry J. Paine	G1193-442TW	Nov. 27, 1917	22,500	22,500
Unexcelled Manufacturing Co	P3275-1127TW	Feb. 22, 1918	4,976	4,976
Total			54,976	54,976
Grand total			128,326	128,691

The changes in design of signal rockets which started on May 13, 1918, were put into effect at the different manufactories as rapidly as possible. Samples were submitted by the manufacturers to meet the requirements. Quantity production on the new types started the latter part of July. Production accepted by Government inspectors up to December 8, 1918, was as follows:

Article and firm.	Cuntract No.	Date.	Contracted for.	Completed.
Mark I. Red:				
Unexcelled Manufacturing Co.	P3273-1127TW	Feb. 22, 1918	28,024	16,000
National Fireworks Manufacturing Co.	P14553-2441TW	Sept. 4, 1918	50,000	11,000
Unexcelled Manufacturing Co.	P15167-2504TW	Sept. 19, 1918	25,000	17,000
Henry J. Paine	P15484-2538TW	Sept. 26, 1918	20,000	17,000
Total			123,024	61,000
Mark I. Green:				
Unexcelled Manufacturing Co.	P3273-1127TW	Feb. 22, 1918	25,904	25,904
National Fireworks Manufacturing Co.	P14553-2441TW	Sept. 4, 1918	50,000	8,000
Unexcelled Manufacturing Co.	P15167-2504TW	Sept. 19, 1918	25,000	25,000
Henry J. Paine	P15484-2538TW	Sept. 26, 1918	20,000	18,000
Total			120,904	76,904
Mark I. Amber:				
Unexcelled Manufacturing Co.	P3273-1127TW	Feb. 22, 1918	5,750	5,750
Mark I. Yellow smoke:				
Unexcelled Manufacturing Co.	P3274-1128TW	Feb. 22, 1918	24,000	24,000
Henry J. Paine	P3574-1236TW	Mar. 1, 1918	39,900	39,900
Total			63,900	63,900
Mark I. White:				
Unexcelled Manufacturing Co.	P3273-1127TW	Feb. 22, 1918	29,000	29,000
Henry J. Paine	P3556-1233TW	Mar. 4, 1918	35,000	35,000
National Fireworks Manufacturing Co.	P14553-2441TW	Sept. 4, 1918	50,000	1,000
Unexcelled Manufacturing Co.	P15167-2504TW	Sept. 19, 1918	25,000	25,000
Henry J. Paine	P15484-2538TW	Sept. 26, 1918	20,000	20,000
Total			159,000	110,000
Grand total			472,578	317,562

In order to aid production the Government started to furnish paper parachutes to manufacturers in September, 1918. Some of these were imported from Japan and some sewed in this country. The contracts let with the production to December 12, 1918, were as follows:

Article and firm.	Contract No.	Date.	Contracted for.	Completed.
28-inch domestic sewed: Japan Paper Co.	P14841-2476TW	Sept. 12, 1918	31,700	31,700
28-inch imported: Japan Paper Co.	P14841-2476TW	do.	27,000	27,000
28-inch domestic sewed: Japan Paper Co.	P15282-2512TW	Sept. 21, 1918	95,000	95,000
28-inch imported: Japan Paper Co.	P15282-2512TW	do.	25,000	23,000
28-inch domestic sewed: Japan Paper Co.	P15405-2532TW	Sept. 24, 1918	1,000,000	230,000
Do.	P15551-2548TW	Sept. 25, 1918	28,700	28,700
Total			1,205,400	435,400
32-inch imported: Japan Paper Co.	P15282-2512TW	Sept. 21, 1918	90,000	90,000
32-inch domestic sewed: Japan Paper Co.	P16310-2657TW	Oct. 9, 1918	630,000	170,000
32-inch imported: Japan Paper Co.	P16418-2671TW	Oct. 15, 1918	1,000,000	90,000
32-inch domestic sewed: Japan Paper Co.	P17797-2815TW	Nov. 6, 1918	400,000	77,700
Total			2,120,000	427,700
34-inch imported: Lewis Nixon	P15402-2529TW	Sept. 24, 1918	103,000	103,000
36-inch imported: Japan Paper Co.	P16961-2716TW	Oct. 22, 1918	210,000	187,500
Flag imported: Japan Paper Co.	P15791-2472TW	Sept. 11, 1918	5,000	5,000
Do.	P16314-2661TW	Oct. 5, 1918	40,000	....
Total			45,000	5,000
Grand total			3,683,400	1,158,600

POSITION LIGHTS.

The first contract for position lights was for the hand type, Mark II, let to Henry J. Paine on December 19, 1917. The first produc-

tion passing Government inspection was the first part of February, 1918. Contracts for the hand type, Mark I, were first let the early part of March, 1918, and by the middle of May quantity production was passed Government inspection. It was necessary for several changes in specifications to be made. The most radical of which were made June 14, 1918, covering formulæ, time of burning, and candlepower. Since that time, the manufacturers adapted their production to the new specifications as rapidly as their samples could be made to pass the necessary tests. Considerable trouble was encountered, but by August 1 the Mark II hand-type position lights had reached a steady maximum quantity production. The Unexcelled Manufacturing Co. were not able to reach quantity production on the ground type Mark I until September, 1918. In the meantime, however, the Nixon Fulgents Product Co. were able to turn out their contract complete by July 20, 1918. The contracts let and production accepted by Government inspection up to December 12, 1918, are as follows:

Article and firm.	Contract No.	Date.	Contracted for.	Completed.
Mark II. Hand, white:				
Henry J. Paine	G1192-441TW	Nov. 27, 1917	50,000	50,000
Unexcelled Manufacturing Co	G1274-472TW	Dec. 8, 1917	50,000	50,000
Do	P3280-1134TW	Feb. 22, 1918	485,000	485,032
Henry J. Paine	P15487-2541TW	Sept. 24, 1918	27,000	27,000
Unexcelled Manufacturing Co	P15554-2549TW	Sept. 27, 1918	30,000	30,000
Essex Specialty Co.	P16250-2651TW	Oct. 10, 1918	50,000	...
Henry J. Paine	P3557-1234TW	Mar. 4, 1918	165,000	165,000
Total			857,000	807,032
Mark I. Ground, white:				
Unexcelled Manufacturing Co	P3275-1128TW	Feb. 22, 1918	132,000	132,002
Lewis Nixon	P3856-1291TW	Mar. 8, 1918	18,000	18,000
Unexcelled Manufacturing Co	P15792-2569TW	Sept. 26, 1918	50,000	...
Essex Specialty Co.	P16250-2651TW	Oct. 10, 1918	100,000	...
Total			300,000	150,002
Mark I. Ground, red:				
Unexcelled Manufacturing Co	P3275-1129TW	Feb. 22, 1918	330,000	330,017
Lewis Nixon	P3656-1291TW	Mar. 8, 1918	45,000	45,000
Do	P13417-2345TW	Aug. 12, 1918	45,000	45,000
Unexcelled Manufacturing Co	P15792-2569TW	Sept. 26, 1918	50,000	50,000
Essex Specialty Co.	P16250-2651TW	Oct. 10, 1918	100,000	12,000
Total			570,000	482,017
Mark I. Ground, green:				
Unexcelled Manufacturing Co	P3275-1129TW	Feb. 22, 1918	198,000	74,017
Lewis Nixon	P3656-1291TW	Mar. 8, 1918	27,000	27,000
Unexcelled Manufacturing Co	P15792-2569TW	Sept. 26, 1918	50,000	...
Essex Specialty Co	P16250-2651TW	Oct. 10, 1918	100,000	...
Total			375,000	101,017
Grand total			12,102,000	1,540,068

RIFLE LIGHTS MARK I, SIGNAL LIGHTS MARK I, AND VB CARTRIDGES.

Production was well under way on contract for 2,000,000 rifle lights, Mark I, and signal lights, Mark I, when on June 13, 1918, the Engineering Division notified us that these articles would have to be

completely changed to the French types. Production was stopped. The French types are known as VB star and parachute cartridges, of which there are about 20 types. Quantity production on these types started about October 15, 1918. The contracts let and production accepted by Government inspection up to December 12, 1918, are as follows:

Article and firm.	Contract No.	Date.	Contracted for.	Completed.
Rifle light, Mark I, white:				
Unexcelled Manufacturing Co	P3271-1125TW	Feb. 22, 1918	265,000	(1)
Lewis Nixon	P3856-1291TW	Mar. 8, 1918	55,000	55,000
Signal lights, Mark I, green:				
Unexcelled Manufacturing Co	P3272-1126TW	Feb. 22, 1918	88,000	(1)
Lewis Nixon	P3856-1211TW	Mar. 8, 1918	55,000	55,000
Mark I, red:				
Unexcelled Manufacturing Co	P3272-1126TW	Feb. 22, 1918	88,000	(1)
Lewis Nixon	P3856-1291TW	Mar. 8, 1918	55,000	55,000
Total			606,000	165,000
VB parachute:				
Lewis Nixon	P3856-1291TW	Mar. 8, 1918	610,000	53,040
VB star cartridge:				
Lewis Nixon	P3856-1291TW	Mar. 8, 1918	605,000	174,420
Total			1,215,000	227,460

[1] Canceled.

SIGNAL LIGHTS, MARK II, VERY.

On January 3, 1918, contracts were let for Remington Arms Co. U. M. C. for 1,000,000 signal lights, Mark II, except stars, and to the National Fireworks Distributing Co., for 1,000,000 stars. These contracts were completed and production well under way on 2,000,000 more, when on May 18 we were notified that the 10 gauge pistol, the ammunition for which is the signal lights, Mark II, would be replaced by the 25 mm. French type pistols. Production was stopped immediately. The contracts let with production accepted by Government inspection up to December 12, 1918, are as follows:

Article and firm.	Contract No.	Date.	Contracted for.	Completed.
Red, Mark II:				
Remington Arms Co	G1802-636TW	Jan. 2, 1918	333,000	307,800
Do	P2473-871TW	Feb. 1, 1918	667,000	576,980
Total			1,000,000	884,780
White, Mark II:				
Remington Arms Co	G1802-636TW	Jan. 2, 1918	334,000	330,400
Do	P2473-871TW	Feb. 1, 1918	666,000	615,480
Total			1,000,000	945,880
Green, Mark II:				
Remington Arms Co	G1802-636TW	Jan. 2, 1918	333,000	294,600
Do	P2473-871TW	Feb. 1, 1918	667,000	425,748
Total			1,000,000	720,348
Grand total			3,000,000	2,551,008

VERY CARTRIDGES, 25 MM.

Contracts were let first for 25-mm. Very cartridges on August 17, 1918. The primed metal cartridge cases were made by one manufacturer and sent to a fireworks plant to be loaded. The Government furnished primers, silk parachutes, metal parts, and in order to facilitate production, it was intended to furnish the loading plant all component parts. Production was well under way on component parts when the armistice was signed. Contracts let with production accepted by Government inspectors to December 12, 1918, were as follows:

Article and firm.	Contract No.	Date.	Contracted for.	Completed.
1 star, red: National Fireworks Co.	P15172–2506TW	Sept. 19, 1918.	100,000	0
1 star, white: National Fireworks Co.	P15172–2506TW	do.	100,000	0
1 star, green: National Fireworks Co.	P15172–2506TW	do.	100,000	0
Total			300,000	
Cartridge cases: Empire Art Metal Co.	P13873–2372TW	Aug. 21, 1918.	2,000,000	836,010
No. 4 commercial primers: Winchester Repeating Arms Co.	P15519–2543TW	Sept. 27, 1918.	25,000,000	4,760,000
24-inch silk parachutes:				
New England Corset Co.	P17024–2727TW	Oct. 24, 1918.	500,000	0
Rose Bros. & Co.	P15187–2508TW	Sept. 20, 1918.	100,000	65,600
Total			600,000	65,000
Metal star containers: Art Metal Works	P16105–2630TW	Oct. 3, 1918.	5,200,000	10

SMOKE TORCHES.

On June 25, 1918, contract was let for 500,000 smoke torches. The first production was not satisfactory, but after several experiments were made, a successful mixture was accomplished. An improvement was made in the tin can. Production accepted by Government inspectors up to December 12, 1918, was as follows:

Article and firm.	Contract No.	Date.	Contracted for.	Completed.
Smoke torches: Nixon Fulgent Products Co	P10700–2114TW	June 25, 1918.	500,000	110,000

WING-TIP FLARES.

The first contract was let August 27, 1918, to Henry J. Paine for 20,000 red and 20,000 white wing tip flares. Considerable delay was caused making a mixture that would give the proper time of burning. A contract was let on June 1, 1918, to Nixon Fulgent Products Co., who were able to meet the specifications. A successful formula was given to Henry J. Paine so that production could proceed without further delay. The contracts let with production accepted by Government inspectors up to December 12, 1918, are as follows:

Article and firm.	Contract No.	Date.	Contracted for.	Completed.
Mark I. red:				
Henry J. Paine	P8741-1971TW	May 27, 1918	20,000	0
Lewis Nixon	P9062-1990TW	June 1, 1919	36,083	36,083
Total			56,083	36,083
Mark I. white:				
Lewis Nixon	P9062-1990TW	June 1, 1919	36,082	36,082
Henry J. Paine	P8741-1971TW	May 27, 1918	20,000	8,000
Total			56,082	44,082

AIRPLANE FLARES.

On May 29, 1918, a contract was let to the Nixon Fulgent Products Co. for assembling of 50,000 airplane flares. The metal casing or bomb, was let to Edward G. Budd Manufacturing Co., Philadelphia, on June 5, 1918. The Government also furnished silk for the parachutes and contracted for the making of the parachutes. Considering the large amount of detail involved, good progress was made in securing silk for the parachutes, making of the parachutes, and the making of metal cases. It was necessary to make several changes in the loading or assembling before the flares would function properly. The contracts let with production accepted by Government inspectors up to December 12, 1918, are as follows:

Article and firm.	Contract No.	Date.	Contracted for.	Completed.
Silk for airplane flares:				
Cheney Bros	P11934-2222TW	July 16, 1918	75,000	75,000
D. G. Dery (Inc.)	P12144-2340TW	do	200,000	147,153
Stehli Silk Corporation	P11894-2209TW	do	101,000	101,000
Sanquoit Silk Co	P11935-2223TW	do	42,000	38,705
Louis Roessel & Co	P11932-2220TW	do	75,000	40,279
Schwarzenbach, Huber Co	P9251-2006TW	June 4, 1918	30,000	30,000
	P9369-2019TW	June 6, 1918	50,000	50,000
	P9923-2059TW	June 13, 1918	50,500	50,500
	P10387-2084TW	June 21, 1918	[1] 25,000	25,000
	P10965-2134TW	June 28, 1918	112,500	112,500
	P11367-2160TW	July 6, 1918	450,000	394,428
	P13567-2354TW	Aug. 15, 1918	75,000	75,000
Duplan Silk Corporation	P11933-2221TW	July 16, 1918	[1] 100,000	92,171
Total			[1] 1,386,000	1,231,728
Parachutes for airplane flares:				
Duplan Silk Corporation	P8912-1982TW	June 5, 1918	1,000	1,000
Follmer, Clogg Co	P9960-2061TW	do	1,785	1,785
	P13629-2358TW	Aug. 16, 1918	2,000	2,000
	P14890-2482TW	Sept. 13, 1918	25,000	13,400
	P12161-2245TW	July 18, 1918	300	[2]
Jacob Gerhardt Co	P13787-2370TW	June 17, 1918	1,500	1,500
	P16313-2660TW	Oct. 13, 1918	10,000	6,094
	P10964-2133TW	June 28, 1918	1,800	1,800
Total			44,385	27,579
Metal cases for airplane flares: Edw. G. Budd Manufacturing Co.	P9321-2009TW	June 5, 1918	65,083	41,020
	P17796-2814TW	Nov. 1, 1918	[2]	
Assembling and loading:				
National Fireworks Co	P17584-2788TW	Oct. 30, 1918	15,000	[2]
Lewis Nixon	P8913-1983TW	June 29, 1918	50,083	3,600
Total			65,083	3,600

[1] Yards. [2] Canceled.

HISTORY OF THE PRODUCTION OF SIGNAL PISTOLS.

VERY SIGNAL PISTOLS, MARK III, 10-GAUGE.

The Remington Arms U. M. C. Co. was given contracts for 35,000 10-gauge Very signal pistols, of which 20,460 were completed when it was decided to change to the 25-mm. Very pistols, Mark IV. Production accepted by Government inspectors up to December 12, 1918, is as follows:

Article and firm.	Contract No.	Date.	Contracted for.	Completed.
Mark III, 10-gauge:				
Remington Arms Co	G720-382TW	Nov. 13, 1917	12,500	12,500
	P5871-1176TW	Apr. 13, 1918	22,500	7,960
Total			35,000	20,460

25-MM. VERY PISTOLS, MARK IV.

On August 5, 1918, contracts were let for 135,000 25-mm. Very pistols, of which 15,000 have been passed by Government inspectors December 12, 1918:

Article and firm.	Contract No.	Date.	Contracted for.	Completed.
25-mm., Mark IV:				
A. H. Fox Gun Co	P13029-2302TW	Aug. 5, 1918	33,057	4,193
National Tool & Manufacturing Co	P13030-2303TW	do	75,000	0
Scott & Fetzer Machine Co	P13031-2304TW	do	30,000	7,750
National Tool & Manufacturing Co	P16311-2658TW	Oct. 13, 1918	28,662	0
Total			166,719	11,943

35-MM. VERY PISTOLS, MARK I, AVIATION.

Thirty-five-mm. pistols, Mark I, aviation, were contracted for the last of August, 1918. Production was well under way when the armistice was signed. Production accepted by Government inspection up to December 12, 1918, is as follows:

Article and firm.	Contract No.	Date.	Contracted for.	Completed.
Die cast parts:				
Dohler Die Casting Co.—				
Handles	P13578-2355TW	Aug. 16, 1918	31,152	5,258
Barrels	P13578-2355TW	do	31,152	4,931
Sides	P13578-2355TW	do	31,152	6,193
Locking piece	P13578-2355TW	do	31,152	4,347
Finished pistols:				
Hammond Typewriter Co	P13325-2330TW	Aug. 10, 1918	15,000	0
Parker Bro	P14453-2431TW	Aug. 29, 1918	14,669	0
Total finished pistols			29,669	0

APPENDIX.

TACTICAL USE OF FOREGROUND ILLUMINATION.

The illumination of the foreground is effected by several means, but the most effective is the searchlight.

TACTICAL USE OF SEARCHLIGHTS.

Considerations.—Depending upon whether the searchlight is used for reconnoitering the dispositions made by the enemy or for combating him, it takes part in the work of exploration or in the action itself. Apart from these two methods of employment, there exists hardly a means of utilizing it with a tactical object. The searchlight is the most effective auxiliary of fire at night. It surprises the enemy, blinds him, and renders him visible, under conditions which depend principally on the hygrometric condition of the air, the diameter of the searchlights, and on the angle of site. By its unforeseen appearance it contributes in delaying and in hindering the advance, and directly to nullify, the intentions of the assailant. The surprise is prepared by the securing of data of prominent points of the terrain during daytime, by means of a special oscillation and inclination device which permits of instantly directing the beam on the point marked.

Independently of the moral effect produced by the surprise, that caused by the dazzling power of the rays prevents the adversary from aiming and firing under good conditions, since it completely prevents him from observing and estimating distances. Furthermore, advance on the searchlight is very difficult. Oscillating illumination (change of direction of the beam from left to right and from right to left) or intermittent (light alternating with obscurity) causes loss of orientation and direction; horses are seized with panic, intrenching has to be suspended, and the enemy is often obliged to discontinue all movement.

* * * * * * *

Moonlight does not reduce as much as would be thought the use of the searchlight, the illuminating power of the searchlight being far greater than that of a full moon. There results an increase of visibility when the searchlight enters into operation. Field searchlights can furnish in normal weather the visibility of the naked eye, and consequently the vulnerability of the adversary at the following distances:

1. *Chemical light apparatus.*—Owing to their low illuminating power these apparatus can operate only with the use of a cylindrical beam. The useful range of these searchlights for the discovery of a group is at from 150 to 200 meters with the naked eye and 250 meters with a field glass. The width of the front illuminated by these apparatus is about 10 meters.

2. *Electric light apparatus.*—Thirty-six-inch electric searchlight, cylindrical beam: Group personnel, with naked eye 1,400 meters; with field glass 2,000 meters; isolated personnel, with naked eye 800 meters; with field glass 1,200 meters. With divergent beam: Group personnel, with naked eye 700 meters; with field glass 800 meters.

Sixteen-inch electric searchlight, cylindrical beam: Group personnel, with naked eye 800 meters; with field glass 1,400 meters; isolated personnel, with naked eye 600 meters; with field glass 800 meters. With divergent beam: Group personnel, with naked eye 500 meters; with field glass 600 meters.

Twenty-four-inch electric searchlight was also available, and later, searchlights up to 60 inches in diameter were available; but these later large types were more particularly designed for use in the rear areas for aircraft detection and illumination.

The distances above mentioned give the degree of visibility of the different diameters of field searchlights, supposing the illuminated troop to be standing and dressed in gray or light blue, the shining parts of the equipment being covered with cloth. At the kneeling position the visibility decreases by one-half; it decreases in still greater portions at the lying position.

* * * * * * *

Light and yellow colors appear white in the luminous beam, green appears yellowish; troops in white and very dark uniforms are easy to discover, for they are well detached

in the luminous beam; gray and light blue uniforms are difficult to distinguish on a green background.

The flashes of arms, tools, buttons, visors of caps render a command very visible. Lights from fires and lanterns are rather difficult to see when they are in the luminous beam.

A fine rain considerably diminishes the range of the searchlight; fog completely checks its action. The same applies to smoke.

Against the dazzling light the only protection is to wear black glasses.

Lowering of visors and leafy branches carried in front give but mediocre results and have the disadvantage of allowing the troops to be discovered by flashes. The eyes of horses appear in the beam like phosphorescent lights.

GENERAL PRINCIPLES ON THE USE OF SEARCHLIGHTS.

* * * * * * *

Long-range searchlights can be employed for the following purposes:

1. Support exploration and contribute to reconnoitering of the terrain.
2. Illuminate objects for fire.
3. Facilitate the march of columns.
4. Mask the movements of friendly troops.
5. Blind enemy searchlights.
6. Blind the adversary.
7. Deceive the enemy by feints.
8. Produce an effect of demoralization.
9. Illuminate work of all kinds.
10. Insure communication between distant detachments and secure for signaling.
11. Aviation.

* * * * * * *

ILLUMINATE OBJECTS FOR FIRE.

* * * * * * *

Artillery fire.—As soon as the object has been discovered, the commander of the battery has the fire prepared for such object, the beam of the searchlight remaining unmasked as little as possible, so as not to draw the fire of the enemy. On firing the salvo the searchlight unmasks for the time necessary for observing the fire and, if required, following the object.

Infantry fire (rifle or machine gun).—

Rifle.—

* * * * * * *

A searchlight engaged should not retire, even under a menacing pressure of the assailant, unless it receives order from the commanding officer of the troops to which it is assigned, the natural role being to illuminate to the last moment.

Machine gun.—

* * * * * * *

The machine guns open fire each time the object is illuminated by the luminous beam.

FACILITATE THE MARCH OF COLUMNS.

* * * * * * *

The searchlight can also illuminate a line of march, the troops marching in the shade by side of the beam.

Owing to the very sensible contrast between the shade and the light, it is difficult to observe, through the luminous beam, what is passing beyond. Searchlights can therefore be used to establish a sort of luminous screen, behind which the enemy can see nothing. For this purpose one or more searchlights are employed, which are placed more or less to the flank according to circumstances.

This method is employed particularly on flat terrain, but is not practicable in broken country or in mountainous country, since the searchlight has to be installed at the same height as the objects to be masked, and the enemy must not be able to discover them by passing above or below the luminous beam.

Another method, but one of delicate application, consists in moving the luminous beam before a troop advancing, to prevent the enemy discovering it.

Blinding the adversary.—It is impossible for troops in face of a searchlight beam to distinguish anything in the direction of the searchlight or in the neighboring directions. It is therefore possible to approach very closely to an enemy blinded in this manner without being seen, and cases may occur in which an attack with the bayonet can be immediately carried out. This effect is increased if the searchlight be oscil-

lated from side to side, and if a succession of violent contrasts be produced by shutting off the light and reestablishing it several times in succession. Troops marching under these conditions generally lose direction and get in disorder. This effect is still more marked with mounted troops.

Deceiving the enemy by feints.—The searchlights having been adjusted and put in action, the attention of the enemy is drawn in their direction, and this is taken advantage of to make a surprise attack from the opposite side.

Effects of demoralization.—The Russians are greatly in favor of this, for they noted these effects at the siege of Port Arthur. At night the men are in a state of nervous tension. When the luminous beam is thrown on them they are dazzled and think they are perceived by the enemy. This fear increases, for they are conscious of being unable to defend themselves, and thus feel their destruction imminent.

* * * * * * *

Communication between detachments—Signaling.—At night the luminous beam is visible at very great distances (12 to 62 miles,) according to its strength.

For signaling, the Morse signals or conventional signals are used. Another method consists in projecting the luminous beam on the clouds. Its trace is seen from a great distance ($43\frac{1}{2}$ to 50 miles).

In daytime the searchlight can replace the heliograph; in this case it has to be oriented.

Aviation.—According to aviators it appears that the zone lighted by the divergent lens is sufficient to enable a belated aeroplane to land without too great difficulty.

METHOD OF USE.

It is much more difficult to employ searchlights judiciously in an attack than in defense, for, while the defender will endeavor to explore and minutely search all the terrain in front of him, the assailant will seek obscurity to execute his movements and obtain surprise effects.

DISTRIBUTION OF SEARCHLIGHTS.

The conditions of a good distribution are that each zone of terrain be illuminated with sufficient intensity. It is according to this rule that, in certain foreign armies, the number of searchlights necessary is calculated at the rate of 1 for each 1,000 yards of front.

Searchlights are preferably employed in groups of two each—one for searching for objects, the other for keeping them illuminated and enabling the fire on them to be properly directed. It is thus possible to continue searching the terrain.

ACTION OF THE SEARCHLIGHT.

For searching the terrain it is necessary to operate by alternating light and obscurity, in order that an enemy can not see the beam coming upon it and have the time to avoid it. One should also operate by "bounds," the searchlight remaining unmasked only for the time necessary to allow the observers to see well the illuminated sector. A continuous illumination attracts the fire of the enemy infantry and artillery and facilitates their aim. By means of the sighting device for height and direction fixed on each searchlight, it will be easy to direct the beam instantaneously on a given point that has been marked during daytime. When troops are reported the surprise by the light and the surprise by the fire should be as simultaneous as possible; the adversary remains illuminated as long as the troops covering him with fire consider useful.

The use of the light of a searchlight as a rallying signal at the moment of shock and even during the action is to be condemned, for the friendly troops will almost always be illuminated the same as the enemy.

* * * * * * *

To embarrass adverse ranging on the searchlight the same can be raised or lowered, varying the intensity of the light by combining changes and variations with periods of obscurity. In this manner changes of position of the searchlight can be simulated.

* * * * * * *

The best position for observing is about 40 meters on the flank and a few meters to the rear of the searchlights.

If, in order to observe better, the officer observer has to advance, he will select a position situated at a lower height than that of the searchlight, so as to be always below the beam.

In case of necessity the officer observer may observe from the position of the searchlight, but must place himself below the cone of light.

* * * * * * *

The observer should impress himself with the idea that the illumination of targets will be the most important task of the searchlight. The dazzling, which in certain cases may produce a considerable effect, will be but secondary.

* * * * * * *

The illumination of the foreground by means other than searchlights is accomplished by various contrivances.

Among those most often used are:

Portable lights (automobile headlights), usually electric, using storage batteries.

Rockets shaped like a cartridge, 6 inches long and 1 inch in diameter, fired from a sort of sawed-off shotgun, the light burning about 20 to 30 seconds.

Rockets, a good deal like those used for fireworks, fired from a tube and burning about three minutes.

Flares thrown to the front and so weighted as to stick in the ground upon landing, burning for varied lengths of time.

Rockets which are attached to parachutes and burn as they slowly descend.

Very lights, which burn about one minute.

Bengal flares.

Balls made of a magnesium compound which are lighted and then thrown to the front, burning about two minutes.

Ordinary torches or lanterns backed with reflectors.

Bonfires built by advance sentinels and lighted by them as they withdraw under pressure of the enemy.

These and other contrivances are used for the illumination of the immediate foreground and are effective at ranges from 50 to 300 yards. Some of the lights may be so arranged as to be tripped and lighted by the enemy as he approaches, or may be lighted by men in listening posts. They are of value only in illuminating the ground for the use of rifle and machine gun fire, and mainly are of use in defense only.

Their tactical use is governed by the condition and extent of the area to be illuminated and the amount of illumination desired or possible, especial effort being made to keep the enemy in the light and one's own troops as much as possible in the shadow.

The time, method, and extent of illumination by means of the above-mentioned methods is a tactical question to be decided by the immediate commanders.

It is to be observed that the agents employed in the illumination of the foreground will be largely governed by the conditions. A searchlight throwing a steady beam or intermittent flashes can be readily located by the enemy and will draw artillery fire. With a circular beam, for distance projection, its area of illumination is limited to the diameter of the beam of light. On terrain which is level or sloping toward the enemy positions, it will illumine friendly positions as well as enemy positions.

The position of chemical searchlights located near the front lines may be changed more readily than large electric searchlights, owing to the lighter equipment.

Flares illumine the general surroundings, rather than the specific objective.

Torches thrown out in front of the lines by hand illumine for a short period only, but additional torches can be thrown out if required.

Illuminating bombs are preferable to rockets, in that the trailing sparks of a rocket give indication prior to the bursting of the illuminating element, and thus give warning which may permit of enemy concealment prior to the burst.

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*599. Forward Illumination in Battle.

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*722. Description and Instruction for the Use of Position Lights, Mark I and Mark II.

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The Effect of Hovering Flares on Visual Target Acquisition

by
MAJ Robert L. Hilgendorf, USAF
S/SGT Robert G. Searle, USAF
Aerospace Medical Research Laboratory
Wright-Patterson Air Force Base
and
Ronald A. Erickson
Naval Weapons Center

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R. G. Freeman, III, RAdm., USN . . . . Commander

G. L. Hollingsworth . . . . Technical Director

FOREWORD

This technical report documents work conducted from January to October 1974 at Wright-Patterson Air Force Base, Ohio and at the Naval Weapons Center, China Lake, Calif., as part of a joint services program on air-to-ground target acquisition funded under authorization ARAB RA 05-75.

The Joint Technical Coordinating Group for Munitions Effectiveness has established a Target Acquisition Working Group (TAWG) under the Joint Munitions Effectiveness Manual/Air-to-Surface Division. TAWG tasks have included the definition of problem areas in airborne forward air controller operations, the description of target markers, summary of existing field test data, the evaluation of mathematical models of target acquisition, the camouflage of targets, terrain and foliage masking, and research on target acquisition by flare light.

This report presents the description and results of a flare experiment that was conducted on a terrain model at the Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base. Part of the data analysis and the report preparation was performed at the Naval Weapons Center.

Released by
PAUL B. HOMER, *Head*
Weapons Systems Analysis Division
9 January 1975

Under authority of
M. M. ROGERS, *Head*
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(U) A laboratory experiment was conducted on a terrain model to assess the effect of a hovering flare on target acquisition performance. One group of subjects was asked to search for targets of opportunity by the light of two hovering flares. Another group searched with two normally descending flares. The hovering flare group found 59% of the targets as compared to 52% by the descending flare group. Although this difference is statistically significant, its operational significance is open to question. The data are shown to be directly related to the area on the ground illuminated by 0.2 footcandle.

CONTENTS

INTRODUCTION

A joint-services Target Acquisition Working Group (TAWG) was established in March 1972 and tasked with pursuing a number of studies of visual, air-to-ground target acquisition. Target acquisition by flare light was one of the areas addressed; a summary report was issued,[1] and three laboratory experiments were conducted on a terrain model.

These experiments were conducted to provide data on possible flare characteristics for use by flare designers. The areas addressed were the possible enhancement of target acquisition performance by (1) a flare stabilized against wind effects,[2] (2) a choice of color of flare light (to be published), and (3) a hovering flare.

This report describes the experiment on a hovering flare and discusses the results in terms of applicability in flare design.

BACKGROUND

The area of ground illuminated to some specified level by a flare is a function of the luminous intensity of the flare and its altitude above the ground. Laswell[3] developed a family of curves showing this ground area-flare altitude relationship for a threshold illumination level of 0.2 footcandle (the 0.2 footcandle value has been used as an "optimal" illumination level by flare developers). A plot of Laswell's relationship is shown in Figure 1 for a 2-million candlepower flare. It is seen that the flare provides a maximum area illuminated by 0.2 footcandle or greater when it is at 1,500 ft above the ground.

---

[1] Aerospace Medical Research Laboratory, Wright-Patterson AFB. *Flare Effectiveness Factors: A Guide to Improved Utilization for Visual Target Acquisition*, by Sheldon MacLeod. Dayton, Ohio, AMRL, November 1973. (AMRL-TR-73-46, publication UNCLASSIFIED.)

[2] ------. *The Effect of Flare Drift on Target Acquisition Performance*, by Russell A. Sorensen. Dayton, Ohio, AMRL, 1974. (AMRL-TR-74-73, publication UNCLASSIFIED.)

[3] Naval Ammunition Depot. *Study of the Optimum Suspension of a High Intensity Parachute Flare*, by J. E. Laswell. Crane, Indiana, NAD, May 1963. (RDTN No. 30, publication UNCLASSIFIED.)

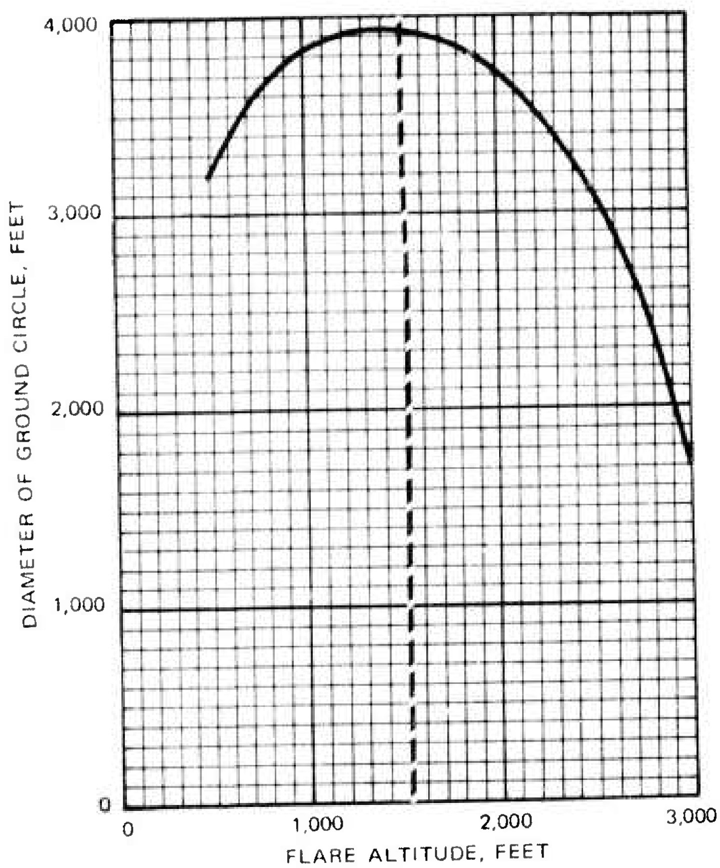

FIGURE 1. Ground Area Illuminated by at Least 0.2 Footcandles from a 2-Million Candlepower Flare.

Hilgendorf[4] has shown in a terrain model experiment that it takes about twice as long to detect targets when they are outside this 0.2-footcandle ring (search time was 1 min inside versus 2 min outside). If a flare is ignited at 2,400 ft and burns out at 500 ft, the circle illuminated by 0.2 footcandle varies from 3,200 ft diameter to a maximum of 4,000 ft and back down to 3,200 ft; the 4,000-ft circle has 1.6 times the area as the 3,200-ft circle.

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[4] Aerospace Medical Research Laboratory, Wright-Patterson AFB. *Visual Search and Detection Under Simulated Flarelight*, by Robert L. Hilgendorf. Dayton, Ohio, AMRL, August 1968. (AMRL-TR-68-112, publication UNCLASSIFIED.)

With these relationships and experimental results in mind, the question arose as to the possible advantage of a flare that could hover at the "optimal" altitude throughout its burning time.

This report describes an experiment where target acquisition performance for targets-of-opportunity was measured for a normally descending flare and a hovering flare. It was hypothesized that the hovering flare would lead to better search performance than the descending flare. The results are useful in assessing the advantages in a hovering flare.

METHOD

Subjects were required to search by flare light for scale model targets located on a model of Central European-type terrain. Flares over the terrain were simulated by suspending small lightbulbs above the terrain, and moving them as required to simulate descent and wind drift. The subjects were "flown" by the terrain at a simulated altitude of 2,000 ft and velocity of 100 knots by a chair-transport mechanism. Their responses were used to compute the mean number, or percent of the targets detected, and the number of errors made.

SUBJECTS

The subjects were 20 male college students with normal color vision and 20/20 or better far and near visual acuity. Color vision was tested by the Dvorine Pseudo-Isochromatic Plates and visual acuity testing was accomplished by the Bausch and Lomb Master Ortho-Rater.

DESIGN

The subjects were divided into two groups of ten subjects each. One group performed with the simulated flares descending normally and the other with the flares stabilized at the "optimal" altitude. This resulted in two groups whose performance data were suitable for testing for statistical significance with the Student $\underline{t}$ distribution. The dependent variables were number of targets acquired and errors.

APPARATUS

Flares

The LUU-2B/B was the flare simulated in this experiment. This flare produces 2-million candlepower for approximately 4 min with an average descent rate of 7.2 ft/sec.[5] Simulation of the flare was accomplished by using a standard No. 47 pilot lamp, but operated 9 volts instead of 6. At this voltage, the lamp produces the proper intensity which simulates 2-million candlepower at a scale of 1:1,000.[6] To simulate the flare descent, the lamps were mounted on a mechanically driven, electronically controlled framework. Two simulated flares were used and they were separated by 5.28 ft simulating a distance of about 1 mile. The flares were ignited in such a way to simulate a flare aircraft flying a track parallel to the flight path of the subject and along the longitudinal axis of the terrain model (Figure 2). An earlier study had demonstrated this deployment concept for the area which was simulated by the terrain model.[7] The descent of each flare was controlled by a 28-volt DC motor. The voltage to each motor is a ramp function to simulate the constantly decreasing velocity in the descent of a parachute flare due to its loss of mass and also due to its heat generation while burning. In addition, a 24-volt DC motor was installed on the descent framework of each flare to provide simulated flare drift due to wind. For the descending condition, the flares were set to ignite at a simulated altitude of 2,400 ft above ground level (AGL) and to burn out at a simulated altitude of 500 ft AGL. Under the fixed condition, the altitude of the flare was maintained at a simulated 1,500 ft. A wind drift of 5 knots was also simulated for both conditions.

Terrain Model

The terrain model, over which the subjects searched for targets, is on a scale of 1:1,000 and provides a reasonably realistic portrayal of Central European terrain. Its dimensions (5 ft x 18 ft) represent a terrain strip approximately 3 miles long by 1 mile wide. The model simulates the color and reflectance properties of the real world within the visible portion of the electromagnetic spectrum and contains a river, road, bridge, and foliage (Figure 3).

---

[5] Eglin Air Force Base. *Functional Test of the LUU-2B/B Aircraft Flare*, by B. G. Ernst. Eglin AFB, Florida, ADTC, April 1970. (ADTC-TR-70-100, publication UNCLASSIFIED.)

[6] North Atlantic Treaty Organization. *Air-to-Ground Target Acquisition with Flare Illumination*, by Robert L. Hilgendorf. AGARD Proceedings No. 100 in Air-to-Ground Target Acquisition, Brussels, Belgium, 1972 (pp. B9–1 to B9–10).

[7] United States Air Force Academy. *Current Research in Simulated Battlefield Illumination: Effects of Flare Shielding*, by Robert L. Hilgendorf. Proceedings of the 2nd Annual Symposium of Psychology in the Air Force. Denver, Colorado, 1970 (pp. 282–295).

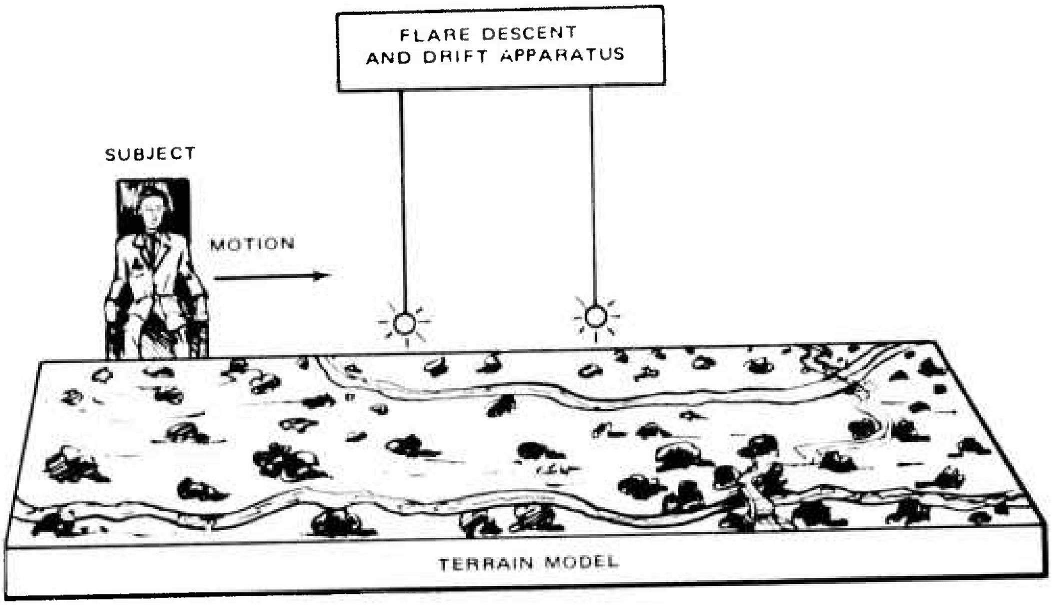

FIGURE 2. Sketch of Terrain Model and Apparatus.

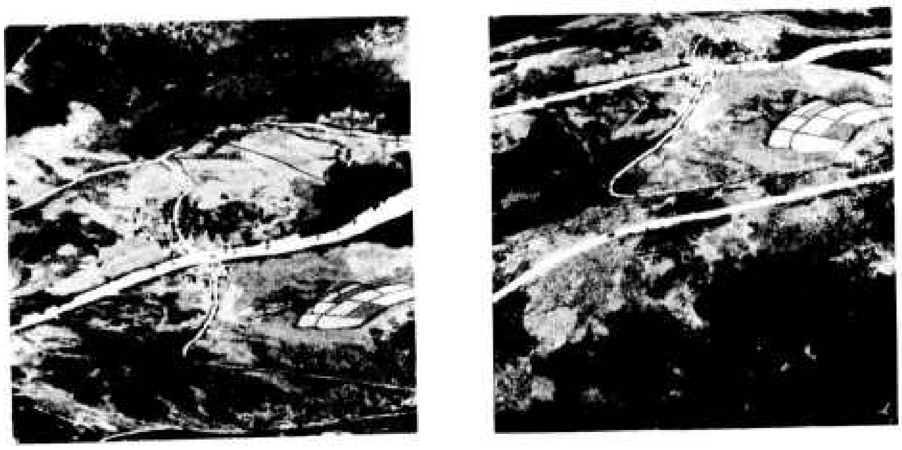

FIGURE 3. Views of Parts of the Terrain Model Used in the Study.

Subject Transport Mechanism

A motorized optometrist's chair was used to "fly" the subject along (beside) the terrain model. The subject wore a helmet with a lock feature, such that the back of the helmet was fixed against the chair's head pads. Through the use of the chair's elevation feature, the eye level of each subject was maintained at a mean of 24 inches above the terrain model's surface to correspond to a simulated altitude of 2,000 ft. Selection of this altitude was based upon a previous study which showed that target acquisition from 2,000 ft was easier than from higher altitudes.[8] The chair was placed on a motorized trolley which propelled the subject along the terrain model at a simulated speed of about 100 knots.

The nondominant eye of each subject was covered by an eye patch to simulate the absence of stereovision, since at the actual ranges which were simulated, there would be no stereoscopic distance/depth cues available.

Targets

The targets were a river, a road, a bridge, a parked truck, a moving truck, a moored boat on the river, a moving boat, and three single tanks. The moving boat and truck were always started from their respective starting points and moved at velocities of 40 mph and 15 knots, respectively. The vehicles and boats were isolated from one another so that there were seven point targets, two of them moving.

PROCEDURE

After initial visual screening and preliminary explanation, each subject was trained to identify the targets listed above. This training was accomplished on a smaller terrain model located in the subjects' preparatory room.

The subject was then brought into the test room, seated, and allowed to adapt to the dark for 15 min. During this time, the instructions were repeated and the subject was asked to name the targets for which he would be looking.

During the actual run, the subject was asked to call out the name of each target as he sighted it. Due to the high learning rate associated with targets on the terrain model, each subject was used for only one experimental trial.

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[8] Hilgendorf, R. L., "Visual Performance with Simulated Flare Light: Effects of Flare-Ignition Altitude," HUMAN FACTORS, Vol. 13, No. 4, 1971, pp. 379–386.

The total number of valid targets found (detected, identified, and located) by each subject and the number of errors (e.g., identifying a truck when there was none in the area) were recorded for each subject. In addition, the time of his report was noted (with $t = 0$ being the start of the trial); this time could be correlated with his location along the terrain model.

RESULTS AND DISCUSSION

Three of the ten targets do not provide any data on differences between search by the hovering and descending flares. The river was reported by all subjects in both groups. Two tanks were never seen by any of the subjects. Performance on the individual targets is shown in Table 1. The performance of the individual subjects across all 10 targets is shown in Table 2.

The hovering flare group found more targets than the descending flare group (59 versus 52); this difference was found to be statistically significant by a t-test for independent means ($t = 1.87$; $p > 0.05$). Both groups committed about the same number of errors: 10 for the hovering flare group and 11 for the descending flare group.

In summary, the results of this experiment did show that more targets were found by the light of two flares hovering at the optimal altitude than by the light of two normally descending flares.

The results of this experiment can be related to the lighting geometry of Figure 1. The produce of (1) the area lighted by at least 0.2 footcandle and (2) the duration of illumination gives one value of the area-time available for search. For one hovering flare, this product is 12×10^6 sq. ft x 4 min, or 48 million sq. ft-min. For a descending flare, the integral of area-time yields about 42 million sq. ft-min or 0.9 of the hovering flare. The subjects found 52 targets by the descending flares, or about 0.9 of the number they found by the hovering flares.

Although two flares were used in this experiment, their 0.2-footcandle circles did not overlap since they were separated by 1 mile. It also should be pointed out that 0.2 footcandle is not a magic number; it was selected rather arbitrarily after some theoretical deliberations, and has only been used as a boundary in one experiment (see Footnote 4). Nevertheless, this experiment has indicated that the area illuminated by at least that level is related to target acquisition performance.

The data tend to support the contention that the hovering flare concept is associated with superior search performance. The practical or operational significance of the results poses another question. Whether or not this performance increase (13% more targets found in this experiment) is great enough to justify development of a hovering flare is a consideration which should be addressed by armament developers.

TABLE 1. Percent of the Ten Subjects From Each Group That Found a Valid Target.

Target	Percent targets found	
	Group with hovering flares	Group with descending flares
River	100	100
Road	90	100
Bridge	70	100
Moving boat	90	100
Parked truck	90	60
Moored boat	90	50
Moving truck	50	10
Tank	10	0
Tank	0	0
Tank	0	0
Average across all targets	59	52

TABLE 2. Number of Valid Targets Located by Each Subject (Ten Targets Possible).

Hovering flare group	Descending flare group
7	5
5	4
7	5
6	6
6	5
7	5
6	5
4	5
5	6
6	6
Mean 5.9	5.2
SD 1.0	0.6

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Describes engineering tests of aircraft flares, surface flares, and photoflash cartridges. The procedures are also suitable for military potential tests, initial production tests, etc. Test phases include safety tests, environmental and handling tests, and performance tests. These test procedures do not apply to photoflash bombs or illuminating projectiles fired from artillery weapons or mortars.

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US ARMY TEST AND EVALUATION COMMAND
TEST OPERATIONS PROCEDURE

AMSTE-RP-702-103
*Test Operations Procedure (TOP) 4-2-130 — 24 August 1984
AD No.

FLARES AND PHOTOFLASH ITEMS

Dist A-1

1. SCOPE. This document describes engineering tests of aircraft flares, surface flares, and photoflash cartridges. The procedures are also suitable for military potential tests, initial production tests, etc. Test phases include safety tests, environmental and handling tests, and performance tests. These test procedures do not apply to photoflash bombs or illuminating projectiles fired from artillery weapons or mortars.

2. FACILITIES AND INSTRUMENTATION. Standard firing ranges and environmental facilities are required. Specialized equipment is covered under the subtests of paragraph 4 and references (TOPs, MTPs, other ref).

3. REQUIRED TEST CONDITIONS.

3.1 Initial Inspection. The test-item packaging is inspected for evidence of damage and deterioration. The name of the contractor, number of contract, date of manufacture, and other pertinent markings are recorded. The weight and dimensions of the package are also recorded. After unpacking, each item is inspected for damage and defects and pertinent dimensions and weight are recorded.

3.2 Sample Size. The sample size for safety testing will depend, as indicated in paragraph 4.1, upon a design review, the extent of prior testing, and the statistical reliability desired. TOP 4-2-504[1] and paragraph 4.6 will aid in this determination. Increased-severity testing is a factor that can reduce sample size. These same factors are considered in determining the number of items for environmental and shock tests and performance tests.

*Supersedes MTP 4-2-130 dated 23 November 1970.
[1]Numbers match those in Appendix B, References.
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3.3 Characteristics Data Sheet. A characteristics data sheet, suitable for the formal report and other uses, is assembled and printed. It consists of a photograph of the test item (exploded or cross-sectional view preferred) reduced in size and combined on a glossy 8- by 10-inch print, with a listing of all principal physical and performance characteristics. Guidance is provided in TOP 4-2-500.[2]

4. TEST PROCEDURES.

4.1 Safety Testing.

a. Safety testing is normally a first phase of the engineering test. The results of the tests are needed to aid in preparing a safety release prior to any testing by military personnel. Safety testing is also used in preparing a safety release if testing is to be conducted at a climatic test site. TECOM Supplement 1 to AR 385-16[3] should be followed in conducting a successful evaluation. It is also normally a part of the initial production test to meet the requirements of DARCOM Regulation 700-34.[4]

b. The approach to a safety test used in TOP 4-2-504 is applicable to flares and photoflash items. The safety testing of flares and photoflash items involves the following steps:

4.1.1 Design Review.

a. Study the design of the test item to determine which components have adequately proven themselves in designs of other pyrotechnics and which are relatively untried and deserving of more attention.

b. Study the test results of similar pyrotechnics and components to determine the extent to which these results may add to confidence in the safety of the flare or photoflash item.

4.1.2 Review of Prior Testing.

a. Review data from tests conducted by the design agency for use in the safety test. Such tests may include both field tests and laboratory tests, many of which may be in conformance with MIL-STD-331A.[5]

b. In addition, consider all field data from engineer design and other tests conducted at proving grounds in determining the statistical confidence in the safety of the item.

4.1.3 Safety Assessment Report. DARCOM Supplement 1 to AR 385-16 requires submission of a safety assessment report from the developer prior to initiation of development testing. Updated safety assessment reports may be requested for subsequent tests.

4.1.4 Safety-of-flight Release. A safety-of-flight release must be obtained from Aviation Research and Developement Command (AVRADCOM) prior to testing a particular flare or photoflash item from an aircraft.

4.1.5 Adequacy of Safety Features. Examine and manipulate external safety devices to ensure that they are adequate and not susceptible to accidental disengagement.

4.1.6 Adequacy of Manufacture.

a. Carefully inspect all items to be used in the safety test to ensure that they exhibit no observable flaws, and that there are no damaged or missing components.

b. Selected items may be subjected to X-ray examination as deemed necessary.

c. Record all observations.

4.1.7 Shock, Vibration, and Environmental Exposures. The number of test items selected for these exposures depends upon statistical considerations, cost and availability of test items, and amount of data available from prior testing of the same or similar items. The test items are subjected to certain standard transportation, rough handling, and climatic tests that simulate the extreme conditions that may be encountered. TOP 4-2-504 may be used for guidance on the number of test items that should be exposed to the various tests which follow.

a. High-temperature storage test.

(1) Subject packaged test items to a 7-day hot-dry cycling test in accordance with TOP 4-2-820.[6] This test simulates the hot-dry (A1) diurnal cycle of AR 70-38.[7]

(2) Sample size will be determined by the quantity per package.

(3) Following the test, examine the package for damage; open it, and examine the test items for damage.

b. High-temperature operating test.

(1) Expose the unpackaged test items from the high-temperature storage test for 24 hours to a temperature equivalent to the highest temperature that the items would realize if exposed to the solar radiation conditions described under the basic hot (A2) conditions in AR 70-38.

(2) This temperature may be obtained through measurements in a solar radiation chamber in accordance with TOP 4-2-826.[8] If this is impractical, a temperature of 63°C will be assumed to be the equivalent temperature.

(3) At the end of the exposure period, examine the test items for damage and exudation, and fire or launch all of them at the conditioned temperature.

(4) Record firing data described in paragraph 4.2.

NOTE: Most items being tested for hot environments are required to operate only under the basic hot (A2) conditions of AR 70-38. If a requirement exists for safety or satisfactory performance in a hot-dry environment, a test under simulated hot-dry solar radiation conditions, defined in AR 70-38 or a 71°C temperature equivalent, is conducted.

c. Low-temperature storage and operating test.

(1) Expose sample determined by packaged quantity for 3 days at -46°C.

(2) Examine the package for damage and the ability to withstand handling at low temperature.

(3) Unpack and examine the test items; recondition as necessary to -46°C, and fire or launch them in accordance with paragraph 4.2.

NOTE: For test items that are required to operate in the basic cold conditions of AR 70-38, -46°C is required for safety purposes only. If the items are safe to fire at -46°C but do not perform satisfactorily, a later test is conducted at -37°C to evaluate performance under cold conditions.

d. Secured-cargo vibration test.

(1) Vibrate approximately 48 packaged test items at 63°C, and vibrate 24 packaged test items at -46°C to simulate transportation in trucks, trailers, and aircraft as provided in TOP 1-2-601.[9]

(2) Following inspection, fire or launch the test items at the test temperatures in accordance with paragraph 4.2.

e. Rough handling test.

(1) Expose approximately 48 test items to the sequential rough handling test described in TOP 4-2-602.[10] The test includes a 2.1-m packaged drop test, a loose cargo test, and a 1.5-m unpackaged drop test.

(2) After inspection, fire or launch all test items at the test temperatures in accordance with paragraph 4.2.

f. Twelve-meter packaged drop test.

(1) Drop two to six packages of test items in accordance with TOP 4-2-601.[11]

(2) Preferably the test items will have most explosive components removed in advance to permit complete inspection to determine the nature and degree of damage to both the packaging and test samples. (See TOP 4-2-601.)

(3) In some instances, the packages are removed from the drop location with remote handling equipment for assurance that such a drop and subsequent handling will not cause detonation and that the items are safe for disposal.

g. Radio-frequency (RF) hazard test. Conduct this test according to requirements documents but only for electrical or electronic fuzes or electrically initiated items. Otherwise test according to the RF specifications for each type of test item.

h. Static electricity test. Conduct this test in accordance with TOP 1-2-511.[12]

i. Electromagnetic radiation test. Conduct this test in accordance with TOP 1-2-511.

4.1.8 <u>Supplementary Environmental and Shock Tests</u>. From the tests below the test director will select those that he deems necessary considering requirements documents, potential use, and prior testing on the same or similar items. He

will normally expose some of the test items to sequences of extreme environments which the materiel could encounter during its life cycle. Appendix A of MTP 4-2-015[13] provides a general approach to sequential testing. These environments may include those of 4.1 above. One sequence would assume that the item will be sent to the arctic, another that the item will be sent to the tropics, and another that it will be sent to the desert. After each exposure all items are examined and a representative sample test fired. The remainder are sent through the next environment of the sequence.

a. High and low operating temperatures. If the test items proved to be safe but failed to perform satisfactorily at either the "hot-dry" or "cold" temperatures of the safety test (para 4.1), but are required to meet only the intermediate temperature requirements of AR 70-38, conduct additional performance tests at the high and low temperatures as described in paragraphs 4.1.7b and c.

b. Solar radiation. This test is primarily for heat effects.

(1) Expose the test items to the intermediate solar radiation conditions of AR 70-38, in the manner prescribed in MIL-STD-810D.[14]

(2) Test is of 5 days' duration.

(3) After 5 days examine test items.

(4) Fire at the equivalent peak temperature. (See TOP 4-2-826.)

c. Salt spray (fog). The purpose of this test is to determine the corrosive effect of an ocean environment; conduct in accordance with MIL-STD-810D.

d. Fungus resistance. If an actual exposure to fungus is determined to be necessary, conduct the test as described in MIL-STD-810D.

e. High humidity. Conduct in accordance with TOP 4-2-820.

f. Water immersion.

(1) Condition the test items to 44°C.

(2) Immerse in water at 18°C.

(3) Leave for 2 hours under 0.9 m of water. (This is the leakage test of MIL-STD-810D.)

g. Sand and dust. Conduct sand and dust tests in accordance with MIL-STD-810D.

h. Rain and freezing rain. The water immersion test is usually adequate to replace rain, but conduct the freezing rain test in accordance with TOP 2-2-815.[15]

i. Temperature shock.

(1) Conduct this test in accordance with MIL-STD-810D, Method 503.2, except that the high temperature will be in accordance with that for the high-temperature operating test described in paragraph 4.1.7b.

(2) Low temperature will be -46°C.

(3) Maximum time for transfer between chambers will be 30 seconds.

j. Air transportability.

(1) Place the test item in an altitude chamber.

(2) Reduce pressure to simulate a 15,240-m (50,000-ft) altitude, and reduce the temperature to -54°C.

(3) Hold conditions for 2 hours.

(4) After 2 hours restore ambient conditions as quickly as facilities permit.

k. Air delivery. Test packaged airdrop items in accordance with TOP 7-2-509[16] and TOP 4-2-509.[17]

l. Safety tests regarding noise, light, chemicals, etc. Conduct these subtests in accordance with MTPs 4-2-132[18] and 4-3-148.[19]

m. Human factors test. Determine man-item interaction in accordance with MTP 4-3-148.

4.2 <u>Performance Tests, Photoflash Cartridges</u>.

4.2.1 <u>Static Test</u>. The purpose of the static test is to determine the light output of the illuminating charge. (See MTP 4-2-132.)

a. Method. Cartridges modified for static firing must be provided by the manufacturer.

(1) Suspend the cartridge 4.6 to 7.6 m above the ground on a line tied between two poles. The exact height depends on the distance required between the cartridge and the light sensors which are placed on the ground.

(2) Employ one or more sensors depending on the number of positions, relative to the cartridge, at which the light output is to be measured.

NOTE: Use photoelectric cells to detect the flash of the cartridge. Each photoelectric cell has two outputs, a digital integrating voltmeter and an oscilloscope. The digital integrating voltmeter indicates the light output in terms of the "light integral" when a suitable calibration factor is applied. The oscilloscope indicates light intensity with respect to time. The vertical deflections of the electron beam can be converted to light intensity by applying a calibration factor. The horizontal sweep rate is controlled by a time-base generator and, therefore, provides a time reference. A polariod camera photographs the trace on the screen to provide a permanent record of the data.

b. Data required. The test results are expressed in terms of the light integral, which is the integral of light intensity with respect to time, over the illumination time span. This value is obtained from the digital integration voltmeter by application of a calibration factor. As a backup, the light

integral may be obtained from the trace of light intensity versus time by measuring the area under the curve.

4.2.2 <u>Ejection Test</u>. The object of this test is to determine whether the cartridge will function and to determine the fuze delay.

a. Method. This test involves actual firing of the cartridges from a ground-based projector.

(1) Orient the projector to fire at an elevation angle of approximately 55°.

(2) Place a photoelectric cell downrange of the launcher but away from the line of fire.

(3) Direct it toward the area where the flash of the illuminating charge should occur.

(4) Shield it from the direct rays of the sun and the muzzle flash of the projector.

NOTE: The fuze delay of photoflash cartridges is of such short duration that an electric counter (capable of measuring time durations as short as 0.0001 second) must be used to record it. The counter receives its start impulse when voltage is applied to the firing circuit of the projector. The stop pulse is provided by the photoelectric cell when the flash of the illuminating charge occurs.

b. Data required. Record the following:

(1) Number of duds.

(2) Fuze delay of those rounds which function.

4.3 <u>Performance Tests, Aircraft Flares</u>.

4.3.1 <u>Surface Tests</u>. Surface tests of aircraft flares are usually limited to providing assurance that the fuze will function properly with the proper delay, not only under ambient conditions, but at the extreme temperatures and following the environmental exposures stipulated in the safety tests.

a. Method. The assurance of proper fuze functioning is required to be certain that it is safe for testing aloft where, because of the extended drop required, most of the testing must be done. The amount of testing performed on the ground will depend upon the amount of usable data already available from prior testing. Ground tests do not use live flares.

b. Data required.

(1) Environmental exposure prior to functioning.

(2) Temperature at time of functioning.

(3) Fuze delay (measured with a stopwatch and reported to 0.1 second).

NOTE: Information on the intensity of flares is usually provided to the proving ground by the developing agency. If there is a requirement that such information be obtained by the proving ground, however, it will be obtained statically in the manner described for photoflash cartridges (para 4.2.1).

4.3.2 Flight Test. Before testing aloft, a safety-of-flight release must have been received (para 4.1.4), the fuze must have displayed no short delays during surface testing (para 4.3.1), and a check must have been made (with inert flares on the ground) of the compatibility of the aircraft's dispensing system with the particular flare under test.

a. Equipment - The type of aircraft, altitudes, and air speeds are governed by the requirements documents. If the altitude at which candle ejection and ignition occur is to be determined, this can be accomplished by observing the flare by cinetheodolite. (See MTP 5-1-031.[20]) Testing of aircraft flares, however, generally consists of timing each event with a manually operated stopwatch.

b. Fuze delay - Measure the time from launch to ejection of the candle from the flare body with a stopwatch accurate to 0.01 second, and record to the nearest 0.1 second. To accomplish this, the pilot of the aircraft gives a countdown, by radio, to an observer on the ground. On the pilot's command, the flare is launched, and the observer starts the watch. The observer stops the watch upon visually observing candle ejection.

c. Burning time - An observer on the ground times the burning of the candle from ignition until the light is no longer visible. The time is recorded to the nearest second. Notes should be made whether the candle burned out in the air, burned out on the ground, drifted out of sight, etc.

d. Other data - Notes should be made of malfunctions such as failure of the parachute to deploy, late ignition of the candle, shroud lines becoming detached, etc. It may be necessary to measure and record other times in the sequence of events, such as the delay from ejection of the candle until ignition of the candle, ejection of the candle until deployment of the parachute, etc. The need for such information depends upon the performance requirements set forth in the applicable guidance documents.

e. Tests following environmental exposures - The above in-flight tests are employed not only for ambient conditions but for performance tests following the environmental exposures of paragraphs 4.1.7 and 4.1.8. For performance data under high- and low-temperature conditions, it is necessary to minimize the length of time between the time of removal from the temperature box and the time of dispensing from the aircraft. The use of improvised temporary thermal insulation is advisable.

4.4 Performance Tests, Surface Flares. Flares exposed to environmental conditions of paragraphs 4.1.7 and 4.1.8 and those tested at ambient conditions will all be tested for performance in accordance with tests below. The testing of surface flares varies, however, depending upon the type of flare and method of activation.

a. Stationary surface flares - Time the duration of burning, and record observations on the intensity of flare, steadiness of burning, etc.

b. Launched surface flares - As applicable, record the following: angle of launch, fuze delay, duration of burning, maximum height reached by the flare, observations on intensity and steadiness of the flare, observations of parachute performance, and height at time of burnout. Additional times and events such as height at parachute deployment and time of first burning can be recorded as needed. needed.

c. Flares with trip wires - In addition to data of a or b above, measure the force to function the flare to the nearest 0.44 N (0.1 lb) with a pull-type spring scale.

4.5 Vulnerability. When a vulnerability test (sometimes called a bullet impact test) is required, conduct the test using 7.62-mm and cal .50 projectiles fired at close range at service velocity.

a. Method.

(1) Fire upon several test items, unpackaged and grouped, with several types of ammunition.

(2) Satisfactory performance requires that the test items not detonate or ignite, and that they be safe to dispose of.

b. Data required.

(1) Number and types of projectiles.

(2) Location of each impact.

(3) Appropriate photographs and description of results.

4.6 Reliability. When a reliability requirement is stated, MTP 3-1-002[21] is used to determine whether the desired reliability was achieved with the desired confidence. A precise definition of satisfactory performance is a prerequisite to a reliability analysis. Make two reliability analyses:

a. Overall reliability which includes a summation of all of the satisfactory and unsatisfactory samples of each subtest.

b. Selected reliability which includes all sample groups except those in which the test items suffered damage or deterioration during environmental or rough handling tests and groups in which statistically significant failures occurred in a particular subtest.

5. DATA REQUIRED. On a round-by-round basis, record the following:

a. All exposure conditions.

b. Performance characteristics of paragraphs 4.2, 4.3, and 4.4.

c. Conditions of launch.

d. Significant weather conditions.

e. Other observations.

6. PRESENTATION OF DATA.

a. Determine the mean and standard deviations of all numerical values for each parameter measured.

b. Determine the effect of environmental exposures and make an evaluation against the requirements documents or specifications.

c. State the results of the safety test.

d. Note any temperature or handling limitations.

e. Make a statistical comparison between the reliability of the test item and that of the control item, particularly if the control item is a standard item being replaced by the test item.

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APPENDIX A
BACKGROUND

Flares and photoflash items are pyrotechnic devices used for illumination. Flares provide illumination of relatively long duration, 1 to 3 minutes, for visual observation and reconnaissance. They are divided into two categories, aircraft flares and surface flares. Aircraft flares are launched remotely from fixed-wing aircraft using a rack, and from rotary-wing aircraft manually using either a static line or dispenser. A parachute is usually employed to prolong airborne time. Surface flares are generally stationary, although some are contained in their own disposable launchers which are used to project them above the area to be illuminated.

Photoflash cartridges provide illumination of short duration (fraction of a second) for photographic reconnaissance. They are used exclusively on aircraft and are fired from a multibarreled projector on an outer-case-type projector.

APPENDIX B
REFERENCES

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26 June 1969

Materiel Test Procedure 4-3-116
U. S. Army Artillery Board

U. S. ARMY TEST AND EVALUATION COMMAND
COMMODITY SERVICE TEST PROCEUDRE

PROJECTILE, ILLUMINATING

1. OBJECTIVE

The objective of this document is to describe the tests conducted to determine the suitability of an illuminating projectile and the degree to which it meets the specifications of the Qualitative Materiel Requirements (QMR's), or Small Development Requirement (SDR's).

2. BACKGROUND

Generally, battlefield illumination is used to provide friendly forces with light to assist in night operations, both offensive and defensive.

Specifically, illuminating projectiles are used for:

a. Lighting areas of suspected enemy activity.
b. Providing light for night adjustment or surveillance of artillery fire.
c. Assisting friendly troops for attacks or patrol activities.
d. Guiding low level tactical bombers on important targets within artillery range.

When properly used, battlefield illumination increases morale of friendly forces, facilitates operations and harasses and blinds the enemy.

3. REQUIRED EQUIPMENT

a. Howitzer of appropriate caliber and model.
b. Standard Ammunition Components (fuses and propellants) compatible with the test projectiles.
c. Firing Range(s).
d. Appropriate Standard Ammunition, for comparative firings.
e. Organizational and Direct Support Maintenance Facilities.
f. Appropriate Firing Tables or Aiming Data.
g. Boresighting Devices.
h. Wire or Radio Communications Equipment, Linking Flash Observation Post, Flash Control and Weapon Position.
i. Transport Vehicles, for Ammunition, Equipment, and Personnel.
j. Meteorological Equipment.
k. Medical Aid Personnel and Equipment.
l. Muzzle Velocity Measuring Devices with Operating Personnel.
m. Surveyed Flash Observation Posts with Operating Personnel.
n. Survey, Personnel and Equipment.
o. Powder Thermometer.

4. REFERENCES

A. AR 385-63, Safety Regulation for Firing Ammunition for Training, Target Practice and Combat.
B. Post (or Test Site) Range Regulations.
C. USAMC Regulation 385-12, Verification of Safety of Materiel from Development Through Testing, Production, and Supply to Disposition.
D. USAMC Regulation 385-24, Range Safety.
E. USAMC Regulation 385-224, AMC Safety Manual.
F. USATECOM Regulation 385-6, Verification of Safety of Materiel During Testing.
G. FM 6-40, Field Artillery Cannon Gunnery.
H. FM 9-1300-203, Artillery Ammunition.
I. MTP 3-3-506, Accuracy and Precision.
J. MTP 4-3-500, Preoperational Inspection and Physical Characteristics.
K. MTP 4-3-501, Personnel Training.
L. MTP 4-3-502, Ammunition Functioning and Reliability.
M. MTP 4-3-504, User Reaction.
N. MTP 4-3-511, Transportability (Ammunition).
O. MTP 4-3-513, Maintenance.
P. MTP 4-3-514, Safety Hazards.
Q. MTP 4-3-515, Human Factors Engineering.
R. MTP 4-3-520, Field Storage.
S. MTP 4-3-521, Training Manuals and Technical Publications.

5. SCOPE

5.1 SUMMARY

This document outlines procedures for service testing of illuminating projectiles in order to evaluate their suitability for use by the Army. The evaluation includes:

a. Preparation for Test - A determination of the condition of the test item upon arrival, its physical characteristics, the availability of facilities, personnel training procedures and safety aspects of the test.

b. Component Compatibility - A study to determine the compatability of the test item with "standard" ammunition components of the appropriate size.

c. Accuracy and Precision and Ballistic Match - A study to compare the ability of the test projectile to match a standard projectile in accuracy and precision.

d. Optimum Height of Burst - A determination of the burst height which will allow the flare to burn out just as it strikes the ground.

e. Debris Pattern - A study of the fall of the metal parts of the projectile to determine if pattern aim can constitute a safety hazard to friendly troops.

f. Effectiveness of Illumination - An evaluation of the effectiveness of the test item in the identification of targets and as an aid in the adjustment of fire.

g. Suitability of Fire Direction Procedures - An evaluation of the recommended firing procedures for obtaining continuous illumination.

h. Field Storage - A study to determine the effect of long-term storage, under various conditions, on the accuracy and reliability of the test item.

i. Transportability - An evaluation of the transportability of the test item and its effect on the accuracy and reliability of the test item.

j. User Reaction - A determination of the reaction of personnel to the use of the test item.

k. Ammunition Functioning Reliability - A study to evaluate the reliability of rounds using the test item.

l. Maintenance Evaluation - A study to determine the maintainability of the test item and an evaluation of the test item maintenance package.

m. Human Factors Evaluation - A study to determine the effectiveness of the test item-weapon-crew relationship.

n. Safety Hazards - A study to determine test item-related safety hazards.

5.2 LIMITATIONS

None

6. PROCEDURES

6.1 PREPARATION FOR TEST

6.1.1 Preoperational Inspection and Physical Characteristics

Upon arrival, determine and record the physical characteristics and operational condition of the test items by subjecting them to the applicable sections of MTP 4-3-500.

6.1.2 Personnel

a. Ensure the availability of service personnel who have been trained using the criteria of MTP 4-3-501 in conjunction with the appropriate technical publications and training manuals of MTP 4-3-521 and are cognizant of the handling, assembling, maintaining, loading and firing, and safety hazard aspects of ammunition and ammunition components, the object of the procedure and the identification and observation requirements of forward observers.

b. Record the adequacy of the supplied training literature.

c. Record the following for all service personnel:

1) Rank
2) MOS
3) Experience in MOS
4) Training Time in MOS

6.1.3 Weapons

a. Ensure the availability of howitzers/guns of the appropriate caliber and tube model(s) which have had average use and which preferably have two-thirds of their tube life remaining.

b. Record the type, caliber and model number of each weapon used.

c. Determine and record the physical condition of each weapon used as indicated by visual inspection, borescoping, and tube wear measurements as

indicated by a pull-over gauge.

6.1.4 Ammunition and Ammunition Components

a. Ensure the availability of sufficient standard ammunition components and standard ammunition to allow for comparative firings, as required.

b. Prior to testing, subject a minimum of 15% of the received test items which have successfully passed the initial inspection procedures of paragraph 6.1.1 to the field storage conditions of MTP 4-3-520 for 90 days.

c. Prior to testing, subject a minimum 15% of the received test items which have successfully passed the initial inspection procedures of paragraph 6.1.1 to the transport conditions of MTP 4-3-511.

6.1.5 Firing Position and Range

a. Select a firing site which shall meet the conditions described in MTP 3-3-506 as concerns range and flash observation posts for accuracy and precision firings (paragraphs 6.2.2, 6.2.7 and 6.2.8).

b. Select a firing site, fairly free of known duds and other debris, that can be entered by personnel without adversely interfering with other units firing on nearby ranges (paragraphs 6.2.3 and 6.2.4).

c. Select a firing site that has a variety of target types (i.e., car bodies, tank bodies, man-size silhouettes - single and in groups to squad size, etc.) set in a variety of terrain (i.e. hills, flat areas, woods, etc.).

6.1.6 Safety

Ensure that a Safety Release, issued as required by USATECOM Regulation 385-6 has been received prior to testing.

6.2 TEST CONDUCT

Note: Normally, when testing ammunition components, only limited quantities of the test item is available, as such all test personnel shall be acquainted with the necessity of accurately gathering maximum data for each round fired. As such, sub-tests shall be conducted concurrently with, or in conjunction with, other subtests, whenever possible.

a. Record the current meteorological data just prior to the start of firing, and at least every two hours thereafter, during testing.

b. Record the following for each round fired, if applicable, to be used for the determination of test item functioning reliability (see paragraph 6.1.10):

1) Height of burst
2) Burning time
3) Time from air burst until flare hits ground
4) Weapon setting
5) Fuze setting

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6) Line of sight (azimuth)
7) Malfunction

6.2.1 Component Compatibility

a. Prior to firing, assemble complete rounds, using the test item, and record evidence of incompatibility of the test item with the following:

1) Propellant charge shell-casing
2) Fuze assembled to the test item

b. Disassemble the items of step a and return them to their packaging.

c. During the firing procedures record any difficulty encountered in setting the fuze on the test round.

6.2.2 Accuracy and Precision and Ballistic Match

6.2.1.1 Preparation for Test

a. Assemble a sufficient number of test rounds, consisting of the test projectiles and standard components, to meet the minimum requirements of the applicable section of MTP 3-3-506.

NOTE: In the event that sufficient ammunition is not available to meet the requirements of MTP 3-3-506, the following schedule, as a minimum, shall be fired:

Charge	Range	No. Rds.
1	50% and 80% Max. Range	40
3	50% and 80% Max. Range	40
5	50% and 80% Max. Range	40
6	50% and 80% Max. Range	40
7	50% and 80% Max. Range	40
Higher Charges	50% and 80% Max. Range	40

b. Assemble "standard rounds", using all standard components, equal in number to the test rounds of step a.

6.2.1.2 Test Conduct

Determine the accuracy and precision of the test rounds and their ballistic match with the standard rounds, using the procedures of the applicable section of MTP 3-3-506 and firing test rounds and standard rounds alternately, and from the same weapon and record the following for each round:

1) Horizontal and vertical location as determined by flash observations.
2) Charge used.
3) Powder temperature
4) For the weapon used:

a) Type, model and caliber
b) Weapon settings

NOTE: 1. This accuracy and precision test will vary slightly from the procedures described in MTP 3-3-506. The ten-round groups will be fired at a point in the air with fuzes set for air burst. Horizontal and vertical location will be made by the flash observation posts. This will save ammunition and permit calculating of range deflection and vertical probable errors from each ten-round group.
2. Ballistic match will have been achieved if the center of comparative groups are within the allowable range, deflection and height of burst probable errors of each other as set forth in the test directive, and they have comparable dispersion patterns. Under these conditions the test projectiles, assembled with standard components, are considered to "shoot" the same as the standard projectiles and is, therefore, suitably accurate.

6.2.3 Optimum Height of Burst

NOTE: 1. Unless otherwise specified in the test item's QMR or training literature, the gunnery techniques of FM 6-40 for determining initial quadrant elevation and fuze setting, shall be used.
2. This portion of the test may be performed in daylight.

a. Using normal gunnery procedures have an observer adjust the height of burst and when the height is approximately correct, perform the following:

1) Fire one six-round group at 50% or maximum range and record the following for each round fired:

a) Location of air burst as determined by flash observation.
b) Time to ejection of flare.
c) Time from ejection until flare reaches ground.

NOTE: This data shall be used in determining flare rate of descent.

d) Burning time for flares that burn out prior to reaching the ground.

NOTE: This data will be used in determining the average flare time of burning. (Flares that reach the ground burning do not burn at the same rate as when suspended by the chute.)

2) Fire a six-round group at 80% of maximum range and record the data of steps a.1.a through a.1.d.

b. Repeat the procedures of step a for all charges.

NOTE: If test ammunition is limited, perform step b for alternating charges (i.e., 1, 3, 5, 7, etc.).

6.2.4 Debris Pattern

Determine the debris pattern of the test item as follows:

NOTE: Since illuminating projectiles are of the base ejection type, their debris pattern can constitute a safety hazard to friendly troops.

a. When sufficient ammunition is available:

1) Fire a minimum of 50 rounds, when weather conditions are relatively stable, at the same quadrant elevation and time setting and record the following:

a) Quadrant elevation
b) Time setting
c) Current meteorological data

2) At the completion of firing have troops search the impact area, recover metal parts from the functioning projectiles and record the location of parts by type with respect to distance from landmarks of known location.

b. When ammunition is not available in sufficient quantity, record the required gun and debris data of step a.1 and a.2 while conducting the optimum height of burst firings of paragraph 6.2.3.

6.2.5 Effectiveness of Illumination

Record the degree of darkness during firing

6.2.5.1 Identification of Targets

a. Fire the test projectiles in accordance with the procedures outlined in FM 6-40 as specified in the QMR or training and technical publications.
b. Have trained observers, using the unaided eye, field glasses, spotting scopes, and other standard observation aids, identify the targets and describe any difficulties encountered.

6.2.5.2 Adjustment to Fire

a. Have trained observers adjust the test projectiles using the prescribed gunnery techniques of FM 6-40 or as specified in the QMR or training and technical publications.
b. At the completion of step a have the observers conduct the adjustment of high explosive shells upon the various targets, using the illumination

provided by the test projectile and record any difficulties encountered.

6.2.5.3 Companion Firings

Repeat the procedures of paragraphs 6.2.5.1 and 6.2.5.2 using standard projectiles and have the observers record their opinions upon effectiveness of the test projectile.

6.2.6 Suitability of Fire Direction Procedures

Determine the proper distance between bursts, and the number of rounds per minute required for continuous illumination as follows:

a. Using the procedures of FM 6-40, or other specified procedures (i.e., QMR, SDR, or other training manuals or technical publications), and the optimum height of burst as determined during the procedures of paragraph 6.2.3, determine the optimum distance between bursts, rounds per minute and height of burst for continuous illumination and record variations from supplied procedures.

b. Photograph the effects of the illumination and record observers' remarks concerning the effectiveness of the continuous illumination.

c. Determine the optimum firing parameters for continuous illumination by repeating the procedures of steps a and b under the following conditions:

1) Increase and decrease the distance between rounds
2) Vary the number of rounds per minute
3) Adjust the height of burst

d. Compare the effectiveness of the test item continuous illumination with standard rounds by repeating the procedures of steps a and b using standard illuminating projectiles.

6.2.7 Field Storage

Determine the effects of field storage on the test item as follows:

a. Record the field storage data of the test items of paragraph 6.1.4.b as described in the applicable sections of MTP 4-3-520.

b. Subject the test items of step a to the accuracy and precision firing procedures of paragraph 6.2.2.

6.2.8 Transportability

Determine the effects of transport upon the test item as follows:

a. Record the transport data of the test items of paragraph 6.1.4.c as described in the applicable sections of MTP 4-3-511.

b. Subject the test items of step a to the accuracy and precision firing procedures of paragraph 6.2.2.

6.2.9 User Reaction

Determine the "user reaction" to the test item during the period of testing as described in the applicable sections of MTP 4-3-504.

6.2.10 Ammunition Functioning Reliability

During the conduct of all firing tests determine the ammunition functioning reliability of the test item and standard item as described in the applicable sections of MTP 4-3-502 and using the data recorded as described in steps a and b of paragraph 6.2.

6.2.11 Maintenance Evaluation

During the period of testing determine the maintenance characteristics of the test item as described in the applicable sections of MTP 4-3-513.

6.2.12 Human Factors Evaluation

Evaluate the effectiveness of the test item-weapon-personnel relationships during the period of testing as described in the applicable sections of MTP 4-3-515.

6.2.13 Safety Hazards

Evaluate the safety aspects of the test item during the period of testing as described in the applicable sections of MTP 4-3-514.

6.3 TEST DATA

6.3.1 Preparation for Test

6.3.1.1 Preoperational Inspection and Physical Characteristics

Record data as described in the applicable sections of MTP 4-3-500.

6.3.1.2 Personnel

Record the following:

a. Adequacy of supplied training literature
b. For all service personnel:

   1) Rank
   2) MOS
   3) Experience in MOS
   4) Training time in MOS

6.3.1.3 Weapons

Record the following for each weapon used:

a. Type

b. Caliber
c. Model Number
d. Physical Condition

6.3.2 <u>Test Conduct</u>

Record the following for each test round fired, as applicable:

a. Test being performed (accuracy and precision, optimum height of burst, etc.).
b. Height of burst in feet.
c. Burning time in minutes.
d. Time from air burst until flare hits ground in minutes
e. Weapon setting.
f. Fuze setting.
g. Line of sight (azimuth) in degrees
h. Malfunction

6.3.2.1 Component Compatability

Record the following:

a. Any difficulty encountered in assembling the test item to the standard components.
b. Any difficulty encountered in setting the fuze and the test rounds

6.3.2.2 Accuracy and Precision and Ballistic Match

Record the following for each round fired:

a. Type of round (test, standard)
b. Current meteorological data
c. Horizontal and vertical location, as determined by flash ranging
d. Charge used
e. Powder temperature

6.3.2.3 Optimum Height of Burst

Record the following for each round fired:

a. Current meteorological data.
b. Charge used.
c. Percent of maximum range fired (50%, 80%).
d. Location of air burst as determined by flash observation.
e. Time of ejection of flare, in seconds.
f. Time from ejection until flare reaches ground in minutes.
g. Burning time, in minutes, for flares that burn out prior to reaching ground.

6.3.2.4 Debris Pattern

Record the following:

a. Weapon quadrant elevation
b. Fuze time setting
c. Current meteorological data
d. Debris pattern location, by parts (see Appendix A).

6.3.2.5 Effectiveness of Illumination

Record the following:

a. Current meteorological data.
b. Degree of darkness during firing.
c. Test (Identification of targets, adjustment to fire, etc.).
d. Projectile used (test, standard).
e. Difficulties encountered, as applicable:

1) Identifying targets
2) Adjusting fire

f. Observer comments on test item effectiveness as compared with standard projectiles.

6.3.2.6 Suitability of Fire Direction Procedures

a. Record the following:

1) Fire direction procedures used (FM 6-40, QMR, SDR, etc.)
2) Changes required in procedures used as regards:

a) Optimum height of burst
b) Distance between rounds
c) Rounds/minute

b. Observer comments on the effectiveness of the test items as compared with standard projectiles.

6.3.2.7 Field Storage

Record the following:

a. Field Storage data as described in the applicable section of MTP 4-3-520.
b. Accuracy and precision firing data as described in paragraph 6.2.2.

6.3.2.8 Transportability

Record the following:

a. Transport data as described in the applicable sections of MTP

b. Accuracy and precision firing, data as described in paragraph 6.2.2.

6.3.2.9 User Reaction

Record data, collected as described in the applicable sections of MTP 4-3-504.

6.3.2.10 Ammunition Functioning and Reliability

Record the applicable ammunition functioning reliability data for the test item as described in MTP 4-3-502 and the data collected as described in paragraph 6.2.

6.3.2.11 Maintenance Evaluation

Record data, collected as described in the applicable sections of MTP 4-3-513.

6.3.2.12 Human Factors Evaluation

Record data, collected as described in the applicable sections of MTP 4-3-515.

6.3.2.13 Safety Hazards

Record safety data, collected as described in the applicable sections of MTP 4-3-514.

6.4 DATA REDUCTION AND PRESENTATION

a. Data obtained from all subtests covered by applicable referenced MTP's shall be summarized and evaluated according to procedures described in those MTP's. Appropriate charts, graphs and tabulated summaries shall be used to present the data in a clear manner. Special consideration shall be given to any condition or circumstance contributing to any test result.

b. Calculations shall be performed as specified by the referenced individual MTP's, wherever applicable. All photographs shall be retained and suitably identified along with other illustrative material.

c. In addition to the items of steps a and b, the following shall be performed and presented:

1) The average burning time for all flares that burn out before reaching the ground shall be determined by tabulating all obtained data.
2) The rate of descent shall be calculated using those flares that burn out after reaching the ground.
3) Chart all probable errors in range, deflection and height of burst and compare the probable errors of:

    a) Test items not stored or transported

b) Test items placed in field storage
c) Test items transported
d) Standard items fired for comparison purposes

4) Analyze and/or categorize for presentation the following:

a) All malfunctions by type
b) Opinions of observers used as regards:

(1) Difficulties encountered in identification of objects and adjustment of fire.
(2) Recommended changes to current gunnery techniques.

5) Compare the test item reliability and present it as a percentage.
6) An overall evaluation of the suitability of the test item for use by the Army shall be made, based on the QMR, SDR, TC or other reliable criteria.

d. Issue a Safety Confirmation, in accordance with USATECOM Regulation 385-6 based on the data collected in paragraph 6.3.2.8.

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NWC TP 5729

The Effect of Illuminating Flare Color on Target Acquisition

by

LT Russell A. Sorensen
MAJ Robert L. Hilgendorf
CAPT Edwin H. Sasaki
Aerospace Medical Research Laboratory
Wright-Patterson Air Force Base, Ohio
and
Ronald A. Erickson
Human Factors Branch
Aircraft Systems Department
Naval Weapons Center

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Naval Weapons Center
CHINA LAKE, CALIFORNIA 93555

Naval Weapons Center

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R. G. Freeman, III, RAdm., USN .... Commander
G. L. Hollingsworth .... Technical Director

FOREWORD

This technical report documents work conducted from January through November 1974 at Wright-Patterson Air Force Base, Ohio, the Naval Ammunition Depot (NAD), Crane, Ind., and the Naval Weapons Center (NWC), China Lake, Calif. The work is part of a joint-services program on air-to-ground target acquisition funded under authorization ARAB RA 05 75.

The Joint Technical Coordinating Group for Munitions Effectiveness has established a Target Acquisition Working Group (TAWG) under the Joint Munitions Effectiveness Manual/Air-to-Surface Division. TAWG tasks have included the definition of problem areas in airborne forward air controller operations, the description of target markers, summary of existing field test data, the evaluation of mathematical models of target acquisition, the camouflage of targets, terrain and foliage masking, and research on target acquisition by flare light.

This report documents a flare experiment that was conducted on a terrain model at the Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base. The flare color simulator was fabricated at NAD, Crane. Part of the report preparation was performed at NWC.

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(U) *The Effect of Illuminating Flare Color on Target Acquisition*, by LT Russell A. Sorensen, MAJ Robert L. Hilgendorf, and CAPT Edwin H. Sasaki, Wright-Patterson Air Force Base, and Ronald A. Erickson, Naval Weapons Center. China Lake, Calif., Naval Weapons Center, February 1975. 22 pp. (NWC TP 5729, publication UNCLASSIFIED.)

(U) A laboratory experiment was conducted on the effect of flare color on target acquisition performance. Subjects were required to search for olive drab model vehicles located on a model of European type terrain. The model consisted of cultural features and predominantly green vegetation. The model was illuminated by one simulated flare whose color was either red, green, yellow, or white.

(U) There were no statistically significant differences between the numbers of vehicles detected or recognized under the different flare light colors. The average ranges at which the vehicles were detected were also about the same for all flare light colors. Although further experimentation should be conducted with other terrains and targets and with haze or smoke in the atmosphere, it has been tentatively concluded that flare color does not affect search performance; existing flare colors are adequate and changing flare color would not improve target acquisition performance.

CONTENTS

ACKNOWLEDGMENT

The contribution to this study of John O'Benar and other personnel from the Naval Ammunition Depot, Crane, Ind. is hereby acknowledged. The flare simulation was designed and built at NAD and the color specifications and color filter response measurements were made there.

INTRODUCTION

A joint-services Target Acquisition Working Group (TAWG) was established in March 1972 and tasked with pursuing a number of studies of visual, air-to-ground target acquisition. Target acquisition by flare light was one of the areas addressed; a summary report was issued,[1] and three laboratory experiments were conducted on a terrain model.

These experiments were conducted to provide data on flare characteristics for use by flare designers. The areas addressed were the possible enhancement of target acquisition performance by (1) a flare stabilized against wind effects,[2] (2) a hovering flare,[3] and (3) a choice of color of flare light.

This report describes the experiment on flare color and discusses the results in terms of applicability to flare design.

BACKGROUND

Various military missions require the visual acquisition of targets by an airborne observer. These missions could include close air support, interdiction, reconnaissance, and the general search for targets of opportunity. Although many automatic methods of target acquisition utilizing sensors are being actively pursued in the research and development community, a significant portion of this task still rests with the unaided human observer. If the task must be accomplished at night, some means of artificial illumination is usually provided and this normally takes the form of air-launched, parachute-suspended, pyrotechnic flares.

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[1] Aerospace Medical Research Laboratory. *Flare Effectiveness Factors: A Guide to Improved Utilization for Visual Target Acquistion*, by Sheldon MacLeod. Wright-Patterson Air Force Base, Ohio, AMRL, November 1973. (AMRL-TR-73-46, publication UNCLASSIFIED.)

[2] Aerospace Medical Research Laboratory. *The Effect of Flare Drift on Target Acquisition Performance*, by Russell A. Sorensen. Wright-Patterson Air Force Base, Ohio, AMRL, 1973. (AMRL-TR-74-73, publication UNCLASSIFIED.)

[3] Naval Weapons Center. *The Effect of Hovering Flares on Visual Target Acquisition*, by R. L. Hilgendorf, R. G. Searle, and Ronald A. Erickson. China Lake, Calif., NWC, December 1974. (NWC TP 5722, publication UNCLASSIFIED.)

Hilgendorf [4,5,6] and Sorensen[7] have investigated the effects on target acquisition of flare separation, flare ignition altitude, observer altitude, flare shielding, and flare drift (due to wind). MacLeod[8] has summarized flare design characteristics, flare and observer position interaction, and other inputs of human factors and their impact on flare effectiveness. However, aside from speculation, there appears to be no empirical evidence dealing with the optimal *color* for a pyrotechnic illuminating flare. Typically, the flare designer has developed the brightest possible flare and normally this resulted in a flare with a radiating spectrum approaching that of an incandescent light source.[9]

Although not directly applicable to the illumination flare consideration, a series of studies were performed which attempted to identify an optimal hierarchy of colors for pyrotechnic markers and signals. The first study[10] involved four colored stimulus lights matched for brightness: light red, green, haze-cutting yellow (minus blue), and clear (incandescent). These stimuli were viewed against four backgrounds: copper, beige, neptune green, and crystal blue, which were chosen to simulate clay soil, desert soil, foliage, and the sea, respectively. In terms of detection times and errors of identification, red and green were associated with better performance than were clear and yellow.

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[4] Hilgendorf, R. L. "Visual Performance With Simulated Flare Light: Effects of Flare Ignition Altitude," HUMAN FACTORS, Vol. 13, No. 4 (1971), pp. 379-386.

[5] Hilgendorf, R. L. "Air-to-Ground Target Acquisition With Flare Illumination," presented at the Advisory Group for Aerospace Research and Development (AGARD) Conference, Brussels, Belgium, June 1972. (Also in *Proceedings 100 on Air-to-Ground Target Acquisition*.)

[6] Hilgendorf, R. L. "In-Flight Validation of a Laboratory Simulation: Visual Acuity Under Flare Light," in Aerospace Medical Association *Preprints of 1973 Scientific Programs*, U.S. Air Force, Las Vegas, May 1973.

[7] Aerospace Medical Research Laboratory. *The Effect of Flare Drift on Target Acquisition Performance*, by Russell A. Sorensen. Wright-Patterson Air Force Base, Ohio, AMRL, 1973. (AMRL-TR-74-73, publication UNCLASSIFIED.)

[8] Aerospace Medical Research Laboratory. *Flare Effectiveness Factors: A Guide to Improved Utilization for Visual Target Acquisition*, by Sheldon MacLeod. Wright-Patterson Air Force Base, Ohio, AMRL, November 1973. (AMRL-TR-73-46, publication UNCLASSIFIED.)

[9] Aerospace Medical Research Laboratory. *Visual Search and Detection Under Simulated Flare Light*, by Robert L. Hilgendorf. Wright-Patterson Air Force Base. Ohio. AMRL, August 1968. (AMRL-TR-68-112, publication UNCLASSIFIED.)

[10] Hilgendorf, R. L. "Optimal Colors for Colors and Signals," presented at a Symposium on Survival and Personal Equipment, Las Vegas, Nev., October 1969. (Also in *Proceedings, Seventh National Flight Safety Symposium*, Vol. 1, Survival and Flight Equipment Association.)

In the second study[11] four additional colors—amber, orange-red, blue-white, and violet—were used and all were evaluated with a terrain model serving as background. The relative positions in the hierarchy of the four colors from the first study held, and violet and amber also were found to be good colors.

The third study[12] was concerned with the in-flight validation of the laboratory experiments. As closely as possible, the details of the scaled-down simulation were duplicated at full scale in a real-world flight test. The agreement between the laboratory simulation and the flight test was exceedingly gratifying. Depending on the criteria used, the correlation coefficients between simulator and field data ranged from 0.77 to 0.93.

In a separate study,[13] the relative preference for six different sighting reticle colors was determined under three conditions: (1) high-level, varying luminance, (2) low-level, varying luminance, and (3) high-level, equal luminance. All colors in each condition were presented by the method of paired comparisons. The results indicated that in the first two conditions, green, orange, and yellow were almost equally preferred. In the third condition, green was most preferred. The background against which the reticles were seen (white, green, or blue) was not a significant factor in reticle color preference.

The above studies dealt with the effects different colors have on the ability of human observers to detect the light sources themselves. However, the question of the effect of the illuminating color on the visual acquisition of nonradiating targets remains topical. Most basic researchers discount the effect of illuminant color on visual color perception because of the principles of color constancy.[14,15,16] Data on detection tasks under different brightness-equated colors appear to be unavailable.

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[11] Hilgendorf, R. L. "An Optimal Hierarchy of Colors for Markers and Signals," in *Proceedings, Eighth Annual Symposium,* Vol. 1, Survival and Flight Equipment Association, Las Vegas, Nev., September 1970.

[12] Hilgendorf, R. L. "Colors for Markers and Signals: An Inflight Validation," in *Proceedings, Ninth Annual Symposium,* Survival and Flight Equipment Association, Las Vegas, Nev., September 1971.

[13] Naval Weapons Center. *Reticle Color Preference as a Function of Background and Luminance,* by Jeffrey D. Grossman. China Lake, Calif., NWC, January 1974. 16 pp. (NWC TP 5610, publication UNCLASSIFIED.)

[14] Judd, D. B., and G. Wyszechi. *Color in Business, Science, and Industry.* New York, Wiley & Sons, 1963, p. 339.

[15] Sheppard, J. J. *Human Color Perception.* New York, American Elsevier, 1968, p. 105.

[16] Burnham, R. W., R. M. Hanes, and C. J. Bartleson. *Color: A Guide to Basic Facts and Concepts.* New York, Wiley & Sons, 1963, pp. 82-85.

METHOD

An experiment was conducted to assess the effect of the color of flare light on target acquisition performance. Model vehicles were placed upon a model of European terrain which included vegetation and cultural features. An electric bulb with the appropriate filter was lighted above the model to simulate a flare, and subjects searched for the vehicles by the flare light. Search and recognition performance was measured for several flare colors.

APPARATUS

Terrain Model

A 1/200-scale European terrain model was used to simulate a land area approximately 1 mile long and a quarter of a mile wide (Figure 1). Typical European cultural and topographical features were represented on the model. Foliage colors were dominated by green, although early fall colors were also used. Spectral and photometric measurements of the paints used on the model correlated with real-world spectral-photometric signatures.

Targets

Only military vehicles were used as targets. Eight tanks and four trucks at 1/200 scale, painted olive green, were positioned on the terrain model. All targets were placed at a 45-deg angle relative to the long axis of the model and at 200-ft increments in slant range as measured from the subject's observation position (see Figure 1). The closest target was placed at the 3,000-ft slant range and the farthest was at the 5,200-ft range. One further restriction in placing the targets was that two or more targets could not fall along the same line parallel to the long axis of the terrain model.

The luminances of each target and its immediate background were measured with a Pritchard 1980 photometer under the white flare light only. The luminance contrast of each target was computed from the equation

$$C = \frac{L_t - L_b}{L_b}$$

where L_t is target luminance and L_b is background luminance (Table 1).

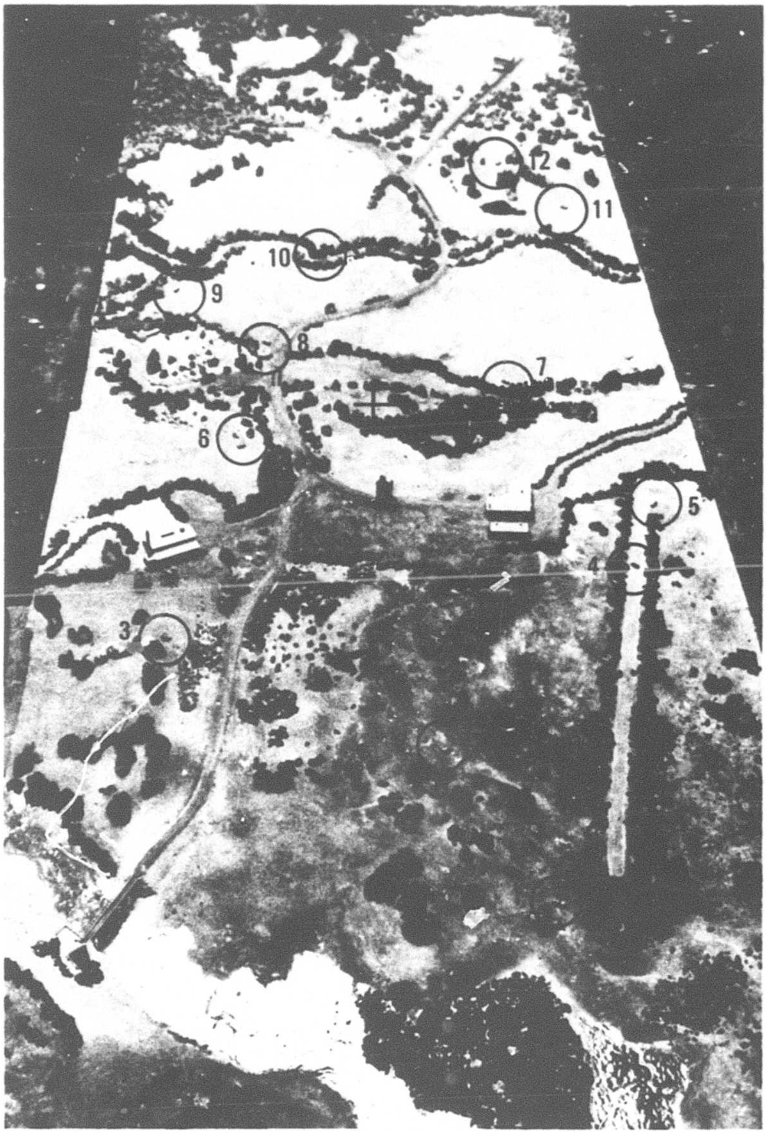

FIGURE 1. Terrain Model and Target Locations. (Cross indicates point over which flare was suspended.)

TABLE 1. Luminance Contrast for Targets Under White Flare Light.

Target No.	Luminance contrast	Target No.	Luminance contrast
1	1.51	7	-0.36
2	0.43	8	-0.21
3	-0.10	9	-0.35
4	0.03	10	-0.37
5	-0.05	11	-0.38
6	-0.27	12	-0.28

Flare Simulation

A 120-V, 600-W, G.E. Quartzline Lamp was used to simulate the pyrotechnic flare. The lamp was suspended from an overhead boom by a bicycle chain. The chain was driven by an adjustable speed motor which allowed the flare to be lowered at a constant rate of 2.7 ft/min. This flare apparatus allowed the simulation of approximately a 750,000-candlepower flare with a descent rate of 7 ft/sec and a burn time of 4 min. Ignition altitude for the flare was determined on the basis of a burnout at 500 ft above ground level (AGL). Only one flare was used over the terrain model and it was positioned exactly over the middle of the terrain. The use of more than one flare over a ground area as small as the one simulated was considered superfluous—a conclusion at least implied in some earlier research done by Hilgendorf (see Footnote 5).

Four flare colors (white, red, yellow, and green) were simulated by the use of colored pyrex filters; the spectral transmissivities of each filter are shown in Appendix A. The luminosity function of the human eye was used to equate luminance for each of the four colors. The voltages to the flare lamp required to achieve equal luminances for all colors were as follows: white, 90.0 V; yellow, 93.6 V; green, 96 V; and red, 120 V.

Subject Response

A Rowi International hand-held light pointer was used by the subject to point out the location of acquired targets. The pointer light was turned on only after a detection response had been made, and turned off immediately after the subject had pointed to the acquired target. While the pointer light was on, the increase in illuminance over the terrain model was negligible.

DESIGN

A completely randomized single-factor analysis of variance design was used. Four levels of flare color were investigated: white, red, yellow, and green. Five measures of observer performance (dependent variables) were used: (1) total number of targets detected, (2) total number of targets recognized, (3) total number of false detections, (4) slant range at first detection, and (5) average detection slant range.

SUBJECTS

Twenty male college students were used as subjects; they had 20/20 or better corrected or uncorrected visual acuity, and normal color vision.

PROCEDURE

Group Assignment

The subjects were divided into four experimental groups of five subjects each. Assignment to a particular group was done on a random basis. The four groups corresponded to the four flare colors used.

Subject Briefing

All subjects were required to read a set of prepared instructions covering their task and appropriate responses during the experiment (Appendix B). Following the reading of the instructions, subjects were allowed to ask the experimenter questions pertaining to the material they had just read. They were then given a black-and-white photograph of the terrain model and required to study the dominant topographical and cultural features of the model. These features were clearly labelled on the photograph. Subjects were asked to use these features when verbally locating a target during the experimental trial. Finally, subjects were shown duplicates of the vehicular targets and reminded that they were only to search for tanks and trucks. A copy of the subject instructions and the photograph used for the briefing can be found in Appendix B.

Experimental Trial

Subsequent to the briefing, subjects were taken to the room where the terrain model was located. The room was partially darkened and the view to the terrain model was obscured. Subjects were shown how to operate the hand-held light pointer and shown the position they were to take during the search task. This position required that the subject rest his chin on a foam pad located on the subject platform above one end of the model. The requirement of the chin rest was necessary to maintain a constant simulated altitude of 2,400 ft AGL.

Following instructions in the use of the light pointer and in the appropriate search position, all room lights were turned off and the subject was dark-adapted for 10 min. Dark adaptation completed, the subject assumed the search position, the flare was turned on, and the 4-min trial was begun. All subject responses were manually recorded by the experimenter. After the 4-min trial, subjects were appropriately debriefed and allowed to leave.

RESULTS

DETECTION AND RECOGNITION

The principal results of the experiment are summarized in Table 2 and Figure 2. The subjects detected from 25% (green flare) to 38% (yellow flare) of the targets. They recognized about 10% of the targets under white, yellow, and green flares, and 19% under red. The data were examined by a single-factor analysis of variance. Although there are differences, there were no statistically significant differences between the scores shown in Table 2 and Figure 2; we must conclude that all flare colors were equally good at providing illumination for target search.

TABLE 2. Means ($\overline{X}$) and Standard Deviations (SD) of the Detections, Recognitions, and False Positives Across Subjects.

Mean No. of	Flare color							
	White		Yellow		Green		Red	
	$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD
Detections	4.00	2.35	4.60	1.52	3.60	2.30	4.00	2.55
Recognitions	1.20	1.30	1.20	1.30	1.60	1.95	2.20	1.92
False positives	2.20	0.84	2.00	1.22	1.40	1.14	1.60	1.82

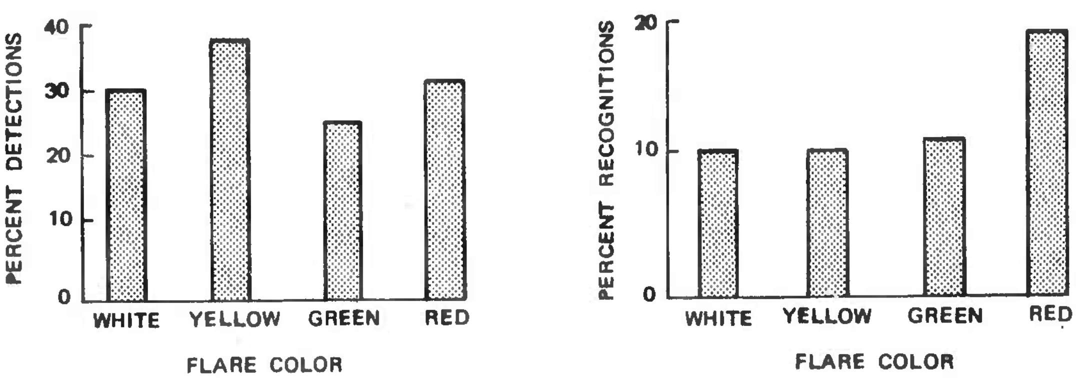

FIGURE 2. Percent Detections and Recognitions for All Flare Colors.

DETECTION SLANT RANGE

The average detection slant range was determined by finding the arithmetic mean of all the slant ranges at detection for each subject (Table 3). The data, in the form of cumulative plots, are also shown in Figure 3. The plots are normalized to positive reports; that is, the computation of percent targets detected is based only upon targets actually detected, not the total possible that could have been detected. This procedure makes it easier to compare the curves with one another.

TABLE 3. Mean Summary Table for Average Detection Slant Range ($\overline{X}$) and Standard Deviation (SD) of Slant Range.

Simulated slant range, ft	Flare color							
	White		Yellow		Green		Red	
	$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD
Average detection	3,620	332	3,840	200	3,890	230	3,430	370

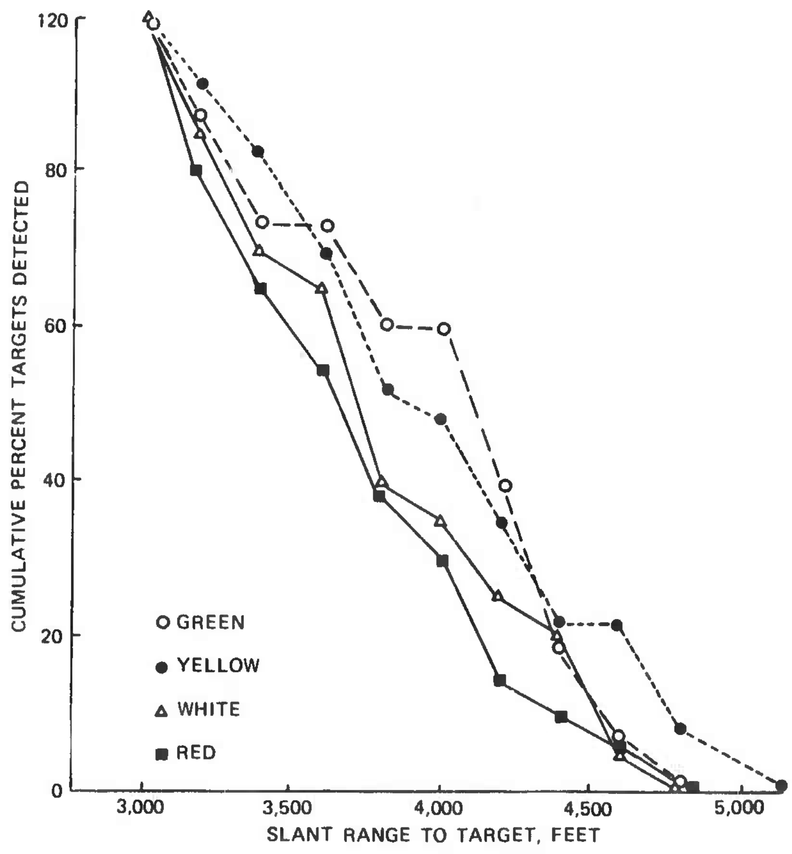

FIGURE 3. Cumulative Percent Targets Detected as a Function of Slant Range. (Data is normalized so that all curves reach 100%; scores are shown in Figure 2.)

Analysis of variance showed no significant differences in average slant range for the four colors. We must conclude that the color of the flare had no effect upon the range at which the targets were detected. Figure 4 shows the distribution of responses for each target summed across colors, and Figure 5 shows the normalized cumulative plot of that distribution. Half of the targets were in front of the flare (that is, between the flare and the observer), but that half accounted for 66% of the detections (see dotted line, Figure 5). Only 34% of the targets beyond the flare were detected; the farthest target was never seen. This drop in detections with range could be because (1) the subjects could not search the length of the terrain model in the time available, (2) the decrease in angular subtense of the target with range (7 to 4 mrad) made detection more difficult, or (3) looking beyond the flare made detection more difficult. Figure 6 illustrates that the subjects had to look very near or through the flare to see the farthest targets; this never had to be done with the nearest targets.

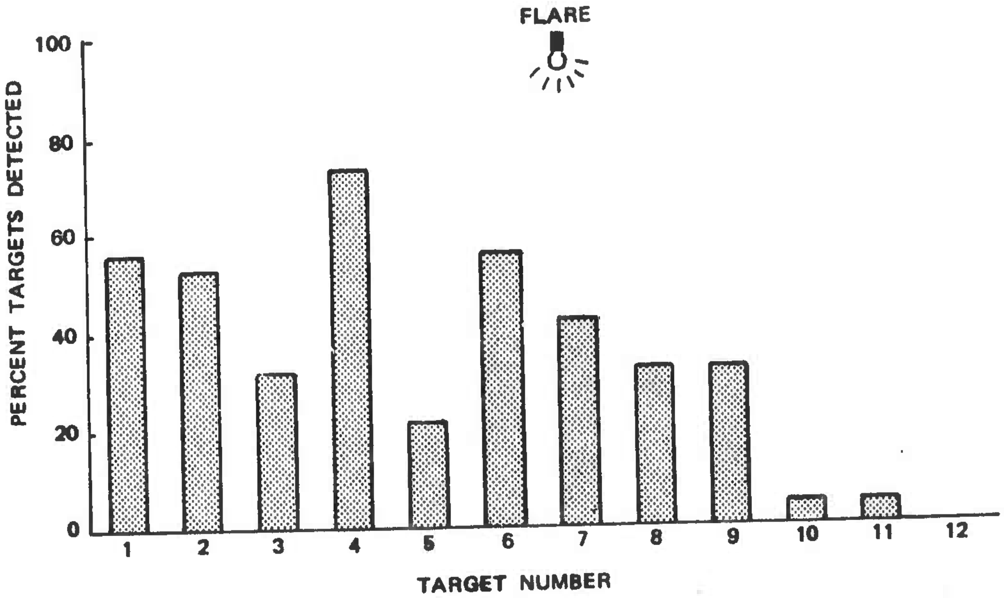

FIGURE 4. Percent Targets Detected Across Subjects. (Target No. 1 was at 3,000 ft slant range; Target No. 12 was at 5,200 ft.)

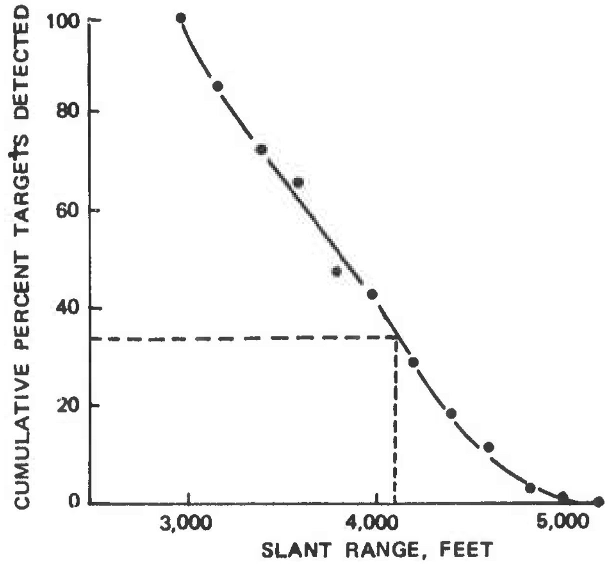

FIGURE 5. Normalized Cumulative Percent Targets Detected as a Function of Slant Range (Data Summarized Across Colors).

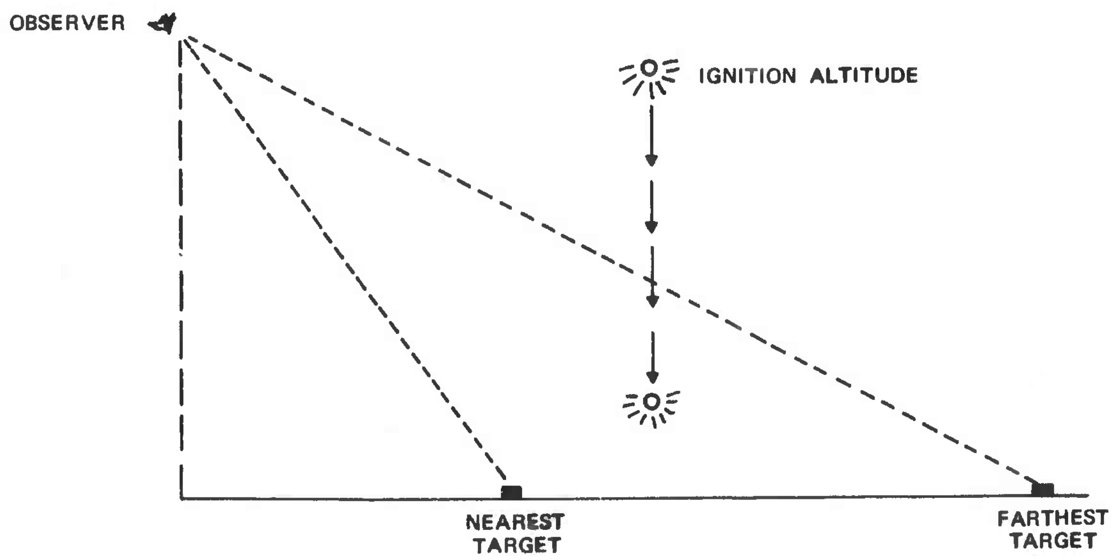

FIGURE 6. Sketch Showing Observer-Flare-Target Geometry.

FIRST DETECTION

The data were examined to determine if the first target detected differed in range for different flare colors. It is seen in Table 4 that the mean range to the first target detected is shortest for the red flare (3,100 ft) and longest for the green flare (3,800 ft).

An analysis of variance (ANOV) performed on the data showed that there was a statistically significant difference (Table 5). A Newman-Keuls test was used to determine which of the means for flare color were significantly different. Results indicated that slant ranges at first detection were significantly shorter under the red flare than under the green flare. All other differences between means were not statistically significant.

TABLE 4. Mean Slant Range ($\bar{X}$) and Standard Deviation (SD) at First Detection.

Simulated slant range, ft	Flare color							
	White		Yellow		Green		Red	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
First detection	3,500	270	3,400	240	3,800	550	3,100	270

TABLE 5. ANOV Summary Table for Slant Range at First Detection.

Source	SS	df	MS	F
Total	84.20	19		
Between (flare color)	33.00	3	11.00	3.44*
Within (error)	51.20	16	3.20	

*$P < 0.05$

DISCUSSION OF THE RESULTS

The results of this experiment imply that flare color does not significantly affect the number of targets detected or recognized. Further, false detections as well as average detection slant ranges were not affected by flare color.

The only performance measure that was significantly affected was slant range at first detection. This last result demonstrated that the subjects tended to make their first detection at shorter slant ranges under red flare light than under green flare light. Since there were no significant differences observed between the white, yellow, and green flares, two conclusions can be drawn from the present study: (1) colored flares as defined in the present research do not significantly improve target acquisition performance when compared to performance under white flare light; (2) red flare light degrades performance relative to slant range at first detection.

Before any definitive statement can be made concerning an optimal color for an illuminating flare, many factors need to be investigated. Future research should consider the interaction effect between colored flares, different terrain colors, and target colors. Since the terrain model used in the present research was primarily green, it was expected that the green flare would produce superior performance. Although this expectation was not verified statistically, the data did indicate a trend in this direction.

Atmospheric transmissivity should also be considered as a factor that might interact with flare color. It is conceivable that, under certain atmospheric conditions, target acquisition may be improved by using a colored flare.

While more research needs to be done in the area of flare color, the present study suggests that the white and yellow-white flares currently being used by the military may, in fact, be the optimal color for an illuminating flare.

Appendix A

TRANSMISSION CURVES FOR FLARE FILTERS

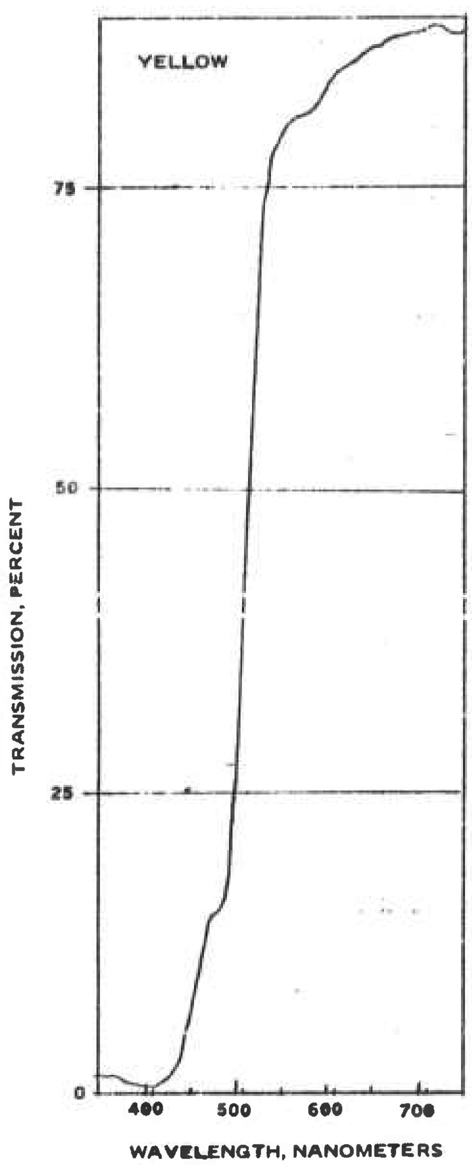

FIGURE 7. Yellow Filter Transmission.

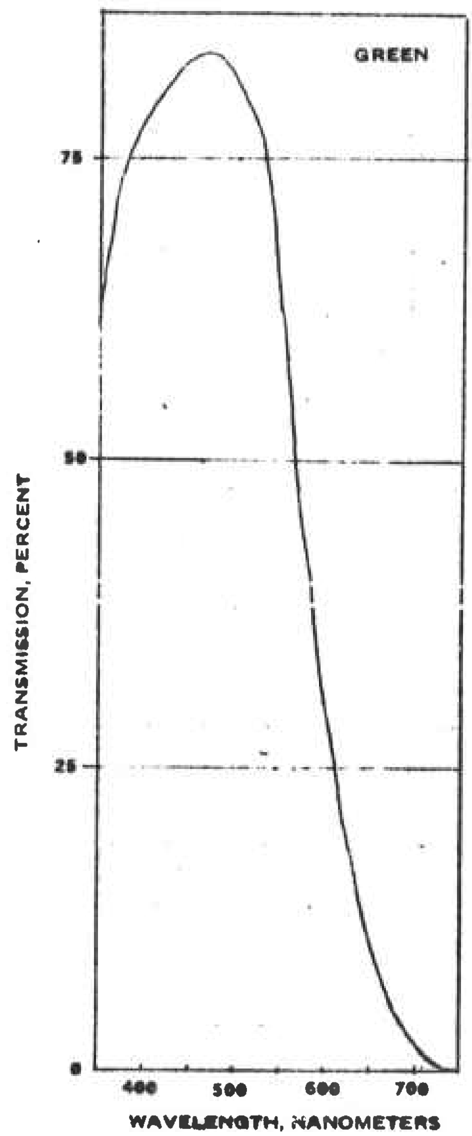

FIGURE 8. Green Filter Transmission.

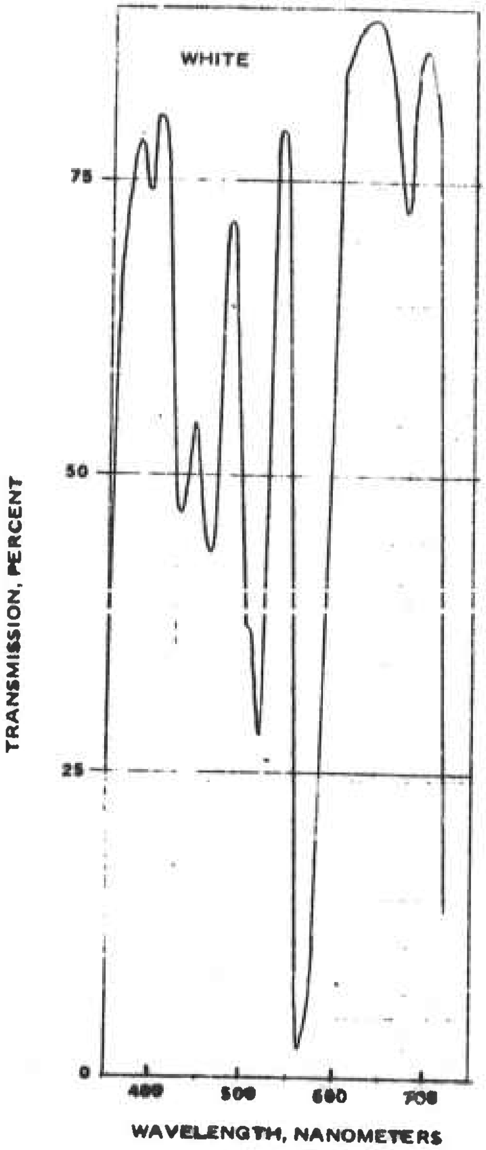

FIGURE 9. White Filter Transmission.

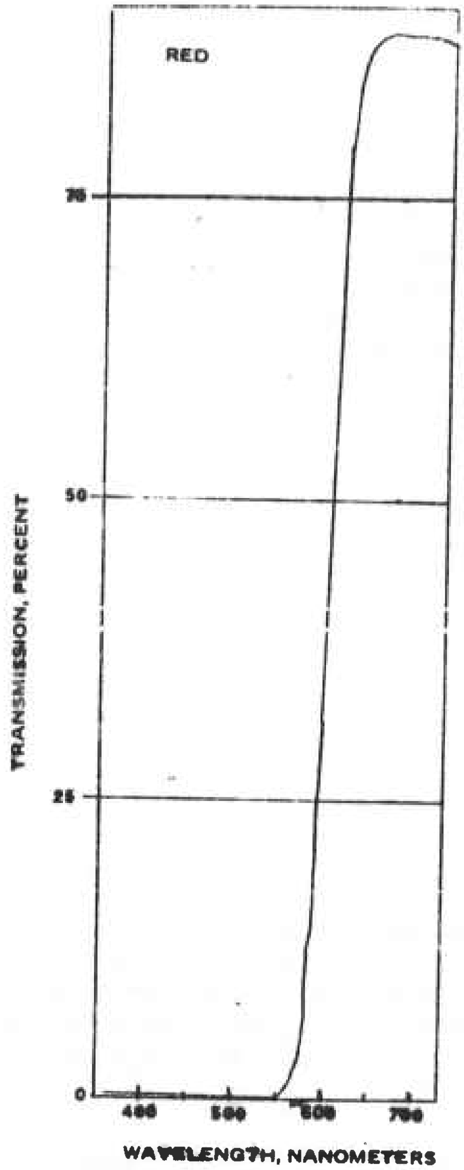

FIGURE 10. Red Filter Transmission.

Appendix B

INSTRUCTIONS TO SUBJECTS

Today, you are being asked to participate in an experiment in which we are trying to determine the effect of the color of simulated flare light upon the detection and identification of targets placed on a terrain model, similar to this one on the table. In this task, you will be an airborne observer, viewing at night, the terrain from approximately this orientation (see Figure 11; note the major landmarks of the terrain). The flare, providing the only illumination for your task, will be positioned to "drop" approximately in the center of the scene. The targets for which you will be searching are of two types–*tanks* and *trucks*–like these on the table. The targets are positioned randomly on the extent of the terrain model.

Your task will be to search the terrain and to locate and identify as many tanks and trucks as you can. When you think that you see a tank or truck, you will point toward it with the flashlight and report verbally its location and whether it is a tank or a truck. For example, if you determine that a tank is located just to the left of depot #1, you will point to the object and tell the experimenter "tank left of depot #1" (or some other very brief descriptive statement). If you think that you see a target, but you can not determine whether it is a tank or a truck, go ahead and point to it and just report to the experimenter "*Target* above depot 2," etc. You will not be told whether your detections are correct or incorrect.

You will have 4 minutes to complete your task. The experimenter will tell you when to start searching and when to stop.

Your primary task is to locate and identify as many tanks and trucks as you can within the time allotted. However, you should also try to keep your errors as low as possible. Errors are of two types–omissions and commissions (false positives). An *omission error* is just that–failure to detect the target. A *false positive error* is the calling of a non-target object, such as, a tree, clump of bushes, pile of rocks, shadows, etc., a target.

Before beginning this task, you will be dark adapted for 10 minutes. This process will adapt your eyes to the darkness which we will use to simulate the night-time condition.

In summary, your tasks are:

1. To locate and identify as many tanks and trucks as you can;
2. To point to the targets and to report verbally their locations and descriptions (tank or truck);
3. To keep errors as low as possible.

Do you have any questions?

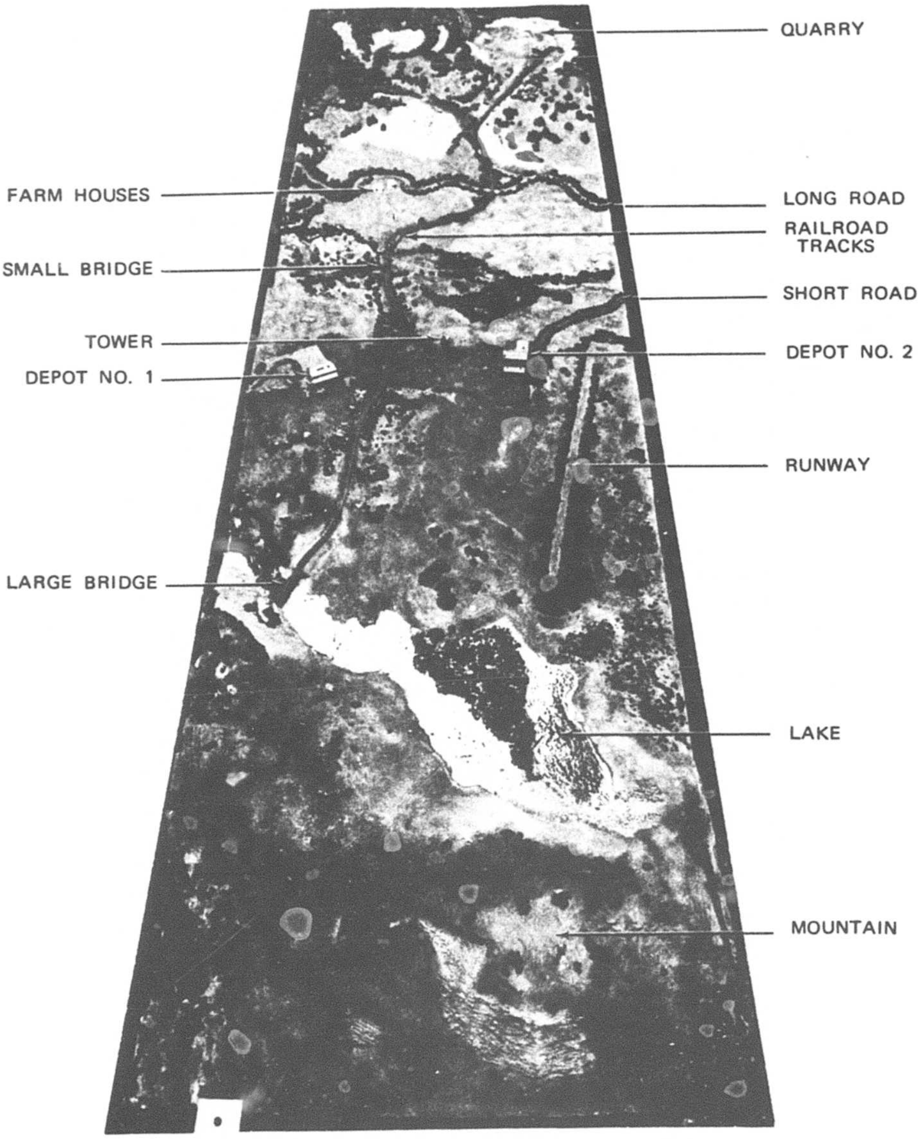

FIGURE 11. Briefing Photograph.

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2

AIR COMMAND AND STAFF COLLEGE

STUDENT REPORT

UNDERSTANDING KC-130 EMPLOYMENT IN SUPPORT OF THE SPECIAL-OPERATIONS-CAPABLE MARINE EXPEDITIONARY UNIT

MAJOR DANIEL RAY HUDSON 88-1295

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TITLE UNDERSTANDING KC-130 EMPLOYMENT IN SUPPORT OF THE SPECIAL-OPERATIONS-CAPABLE MARINE EXPEDITIONARY UNIT

AUTHOR(S) MAJOR DANIEL RAY HUDSON, USMC

FACULTY ADVISOR LIEUTENANT COLONEL WILLIAM HAMMERLE, ACSC/CAM

SPONSOR MAJOR JOE RIGISH, II MAF SOTD

Submitted to the faculty in partial fulfillment of requirements for graduation.

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KC-130 aircraft can be successfully and effectively employed in the support of the Marine Expeditionary Unit, Special Operations Capable. The article will outline the mission of the Marine Expeditionary Unit, Special Operations Capable and examine the capability of the KC-130 to perform this mission. Special attention will be given to those tasks that the aircraft is particularly suited to perform as well as personnel, equipment, and training shortfalls that limit the KC-130's ability to perform special operation missions.

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PREFACE

This article addresses the missions and capabilities of the Marine Expeditionary Unit Special Operations Capable (MEU (SOC)) as related to the mission capabilities of the Marine Corps KC-130. The MEU (SOC) is capable of performing a variety of maritime missions that require specific air support. The KC-130 is a valuable asset to the Marine commander. The KC-130 Hercules and its crew can perform a variety of missions but there are limitations which must be understood if this asset is to be used in special operations missions.

Problem areas within the Marine Air Refueler Transport (VMGR) community will be discussed. These areas include equipment, aircrew training, administration, and their their relationship to the KC-130's ability to perform MEU (SOC) missions. Special emphasis must be placed on efforts to solve these problems. Subject to clearance, this manuscript will be submitted to Marine Corps Gazette for consideration.

The author wishes to thank the following: Major Joe Rogish, who sponsored this project; Lt Col William Hammerle, who served as advisor and provided guidance and direction; and Mrs Bowick for her typing support. The author also thanks the numerous individuals from the Marine Corps VMGR community for their support and encouragement throughout this effort.

ABOUT THE AUTHOR

Major Daniel R. Hudson graduated from Arkansas Polytechnical University in 1972 with a Bachelor's Degree in Education. He completed pilot training at Naval Air Station, Meridian, Mississippi in 1977 and was assigned to Marine Refueler Transport Squadron 352 at Marine Corps Air Station, El Toro, California, where he flew the KC-130F and KC-130R. In 1979, he was assigned to Marine Refueler Transport Squadron 152, Okinawa, Japan. Major Hudson was assigned to Navy Training Squadron 19 at Meridian, Mississippi from 1980 to 1983. He attended Mississippi State University and received a Master of Arts Degree in Education in 1983. Major Hudson attended Marine Amphibious Warfare School (AWS) in 1983. After graduation from AWS in 1984, he was assigned to VMGR-352 and deployed to VMGR-152 during 1986. He has attended the Marine Corps Weapons and Tactics Instructor School at Yuma, Arizona and has served in a wide variety of KC-130 related billets to include squadron operations officer and squadron Safety and Standardization Officer.

Currently, Major Hudson is attending Air Force Air Command and Staff College at Maxwell Air Force Base, Alabama. Upon graduation Major Hudson will be assigned to the First Marine Aircraft Wing, Okinawa, Japan.

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AUTHOR(S) MAJOR DANIEL R. HUDSON, USMC

TITLE UNDERSTANDING KC-130 EMPLOYMENT IN SUPPORT OF THE SPECIAL-OPERATIONS-CAPABLE MARINE EXPEDITIONARY UNIT

I. Purpose: To address the capability of the Marine KC-130 aircraft to perform the mission requirements of the Marine Expeditionary Unit, Special Operations Capable.

II. Problem: Ground component commanders do not comprehend the capabilities of the KC-130. Likewise, they fail to realize the Marine KC-130 and its aircrew are neither trained nor equipped to perform the full spectrum of special operation missions. Commanders must know what missions the KC-130 can successfully accomplish and not have unrealistic expectations of this aircraft's capabilities.

III. Objective: The KC-130 is one of the most versatile aircraft within the Marine Corps inventory. It is a valuable asset to any commander, but its specific attributes and limitations must be thoroughly understood by those who intend to use it. By comparing the missions and capabilities of the Marine Expeditionary Unit, Special Operations Capable to those of the Marine KC-130 and crew, it can be clearly established that this aircraft can perform some, but not all, special operations requirements. The special operations capabilities of the KC-130

CONTINUED

are limited due to its primary air refueling mission. Certain equipment and flight characteristics are of great importance and lend well to some but by all means not every special operations scenario. Commanders of KC-130 squadrons must know what is expected of their aircraft and aircrews in the special operations area. This dictates two-way communication between the ground commander and the aircraft operators in order to establish equipment procurement priorities, aircrew training, and viable related support.

IV. Conclusions: The KC-132 aircrews must be prepared to perform special operations. These special operations can be conducted in a no-threat environment. The KC-130 lacks the equipment to conduct operations into non-lighted airfields or fly night low-level missions. Rapid ground refueling, air refueling, and long-range assault support missions are those which the KC-130 is particularly suited to support special operations.

V. Recommendations: The Marine Expeditionary Unit, Special Operations Capable commander must employ the KC-130 effectively. If he fails to use this aircraft in the correct manner a valuable asset, the KC-130, could be lost either through lack of commitment or through combat attrition. The Marine Corps needs to procure the equipment required for the KC-130s in this expanded role of special operations. However, fiscal realities must be closely considered. Probably the greatest gain in capabilities can be made through an aggressive aircrew training plan. This plan needs to encompass the following areas: (1) expanding current training; (2) embarking into new areas of training; and (3) dedicating a higher percentage of the total flight time to aircrew training. Gains can be made in the combat effectiveness of the KC-130 if a holistic approach to this program is properly initiated and maintained.

Chapter One

BACKGROUND

In August of 1954 a new aircraft was rolled out of Hangar C-1 of the Lockheed Aircraft, Burbank, California facility (1:77). This aircraft was destined to be one of the finest transport and utility aircraft ever produced. It has been built in various configurations, sold to many countries, and flown by the United States Air Force, Coast Guard, Marine Corps and Navy. This aircraft will carry the U.S. military into the 21st century and is still produced by the Lockheed Company at Marietta, Georgia. Those familiar with this description will recognize the aircraft as the C-130 Hercules.

1961 saw the United States Marine Corps take delivery of its first KC-130F, an air refueling model of the standard C-130. This version was designed, manufactured, and produced to satisfy all of the air refueling requirements of the Marine Corps. The Hercules was also capable of performing the transport duties of the standard C-130. Shortly after its induction into the fleet of Marine aircraft, the Hercules proved itself in combat. Throughout the Vietnam conflict, the KC-130 was a valuable asset to the Marine Corps, providing air refueling to Marine and Navy aircraft while furnishing combat assault support to isolated battle sites such as Khe Sanh (1:381). The Marine Corps received its first KC-130R, an updated version of the original Marine Hercules in 1975. This new aircraft did not replace the older KC-130s but augmented existing squadron aircraft. The improved Hercules had updated navigation and communications equipment to include an inertial navigation system, Omega and new UHF, VHF and HF radios, and was also capable of carrying 18,000 additional pounds of fuel (3:121). During the 1980s the US Marine Corps began procurement of the latest version of the "Marine Tanker," the KC-130T, a state-of-the-art aircraft with upgraded radar, radios, and instrumentation.

Since its introduction into service the KC-130 has been a valuable asset to the Marine combat commander. The Hercules was used primarily as a tool to satisfy the air refueling needs of the Air Combat Element Commander (ACE), and has been increasingly used by the Air Ground Task Force commander to support the concept of special operations. Other countries besides the United States have demonstrated the effective use of the C-130 to support special operations. Examples of special operations use of the C-130 include the Entebbe raid of 1976 performed by Israel

to free hostages, and the United States' use of the C-130 in the ill-fated Desert One Operation. The Desert One Operation, although unsuccessful, demonstrated that C-130s could be used to ground refuel helicopters during special operations. In order to increase combat effectiveness, the commander must emphasize the best utilization of all his assets to include the KC-130 aircraft. This effective utilization of assets applies to normal and special operations.

With the increased interest in special operations, the aviational and ground operational commanders must know when, where, and how to most effectively use the KC-130 aircraft. This is accomplished by first understanding the capabilities of the aircraft and aircrews. Translating these factors into how this system relates to mission requirements of the MEU (SOC) is the next step. This essay will be an examination of the MEU (SOC) and the KC-130 missions and capabilities and provide for a thorough understanding of the role the Hercules can and will play in special operations. In addition, current and potential problem areas as well as future integration of the KC-130 system into special operations planning and execution, will be explored.

Chapter Two

THE MARINE AMPHIBIOUS UNIT, SPECIAL OPERATIONS CAPABLE MEU (SOC), HISTORY AND MISSION

Conceptually, the United States Marine Corps operates as a Marine Air Ground Task Force (MAGTF) consisting of ground, air and service support elements. The MAGTF's size and structure are dependent upon its task. The Marine Expeditioary Unit (MEU), the smallest organization of the MAGTF, consists of a battalion-size combat force with aviation and combat support elements of parallel strength. A MEU is capable of performing the following missions (2:2-25):

1. Commitment as an advance force for a larger follow-on MAGTF.

2. Conduct of amphibious assault operations of limited duration.

3. Conduct of amphibious raids.

4. Conduct of humanitarian assistance/disaster relief.

5. Protection and evacuation of noncombatants.

6. Reinforce combat elements by surface or airlift.

7. Provide air support, fire support, combat service support, or other military assistance to allies.

These missions have been the cornerstones for Marine actions for many years and will continue as a basis for amphibious doctrine.

The early 1980s saw the Marine Corps' leader become increasingly concerned with unconventional threats to the security and interests of the United States (2:2-1). A reevaluation of the threat indicated that a definite increase in state-sponsored terrorism existed. Terrorists were found to be highly trained and equipped, capable of performing activities ranging from bombings to the taking of large groups of hostages (2:2-1). The Deputy Secretary of Defense, realizing that the United States must be able to respond to terrorist activities, began to revitalize the nation's special operations capability in 1983. The following year the Commandant of the Marine Corps, General P. X. Kelley, directed that the Commanding General of Fleet Marine Force

Atlantic (CG FMFLANT) evaluate the special operations capability within the Marine Corps (3:2-1). CG FMFLANT found that the Marine Corps possesses certain special operations capabilities (3:2-1). The Marine Corps found that its combination of air, artillery, armor, infantry and combat service support elements under one commander lends itself well to special operations. This unity of command that includes a combination of supporting arms, provides a unique capability to perform operations on very short notice. This quick reaction capability relieves some of the problems associated with coordination, control, and positioning of combat troops.

Based on these findings, the Marine Corps Expeditionary Unit, Special Operation Capable (MEU [SOC]) concept was conceived in 1985 and a pilot program introduced (3:2-2). Additionally, the MEU (SOC) was able to perform the amphibious raid within six hours at night over the horizon, using various means of transport to include helicopters, rubber rafts, raiding craft, and others. A MEU (SOC) composition also enables recovery operations to be executed in a timely manner (2:20). These recovery operations are performed clandestinely or conventionally and include a range of actions from recovery of prisoners of war to the evacuation of noncombatants. The MEU (SOC) can specifically execute the tactical recovery of aircraft and crews in a hostile area and execute the <u>in-extremis</u> hostage rescue when other forces are not available (2:20). Other special mission capabilities include: (1) mobile training teams that will provide instruction to include evacuation operations, small unit anti-terrorist, weapons skills and other areas of training to non-US military units; (2) civil affairs operations; (3) short notice security/reinforcement operations throughout the world; (4) the global maritime ability to rapidly show force; (5) military operations in urban terrain; (6) tactical military deception operations; and (7) other special operations support capabilities (3:42). It must be emphasized that the MEU (SOC) operates in a <u>maritime environment</u> with the seagoing assets of the United States Navy and Marine Corps. The MEU (SOC) was not conceptualized to perform certain specialized operations. The Marine Corps does not plan on performing surgical counter-terrorist hostage rescues, establishment of escape and evacuation networks, psychological operations, sabotage, or subversion (3:4-4). Likewise, the MEU (SOC) is not in competition with the Joint Special Operations Command.

This overview of the MEU (SOC) illustrates how the Marine Corps responds to a changing threat environment that requires special training and special equipment to successfully accomplish its mission. The following chapters will examine the Hercules aircraft system including aircraft, equipment, and aircrew in order to establish viable expectations with regard to MEU (SOC) missions and KC-130 capabilities.

Chapter Three

MARINE AERIAL REFUELER TRANSPORT SQUADRONS AND THE KC-130 MISSION

C-130s in the United States Marine Corps are organized into three active duty, one training, and two reserve aerial refueler transport squadrons (VMGR). Each active operational VMGR squadron operates 12 KC-130 aircraft.

Marine Corps Manual 5-1 states that the mission of the VMGR squadron is to provide aerial refueling service in support of Fleet Marine Forces (FMF), assault air transport for personnel, equipment, and supplies, and to conduct other air operations as directed (5:40). To support these missions VMGR squadrons perform the following tasks:

(1) Air refueling

(2) Assault air transport

(3) Air delivery

(4) Long-range support

(5) Casualty evacuation

(6) Command and control

(7) Ground refueling

(8) Illumination (5:41)

Primarily, the Hercules functions as the commander's in-flight refueler. Refueling operations are commonly conducted in a day/night low-level and emission-controlled (no communication) environment. VMGR squadrons were originally established to function as air refuelers and this fact must never be neglected.

Hercules squadrons are highly qualified to provide air transport of air-landed troops and combat cargo between a logistic air head and small combat airfields. Fields as short as 3,000 feet can be utilized. This support capability within an objective area exists for both day and night operations; however, minimal lighting is required. Portable, battery-powered runway lights can provide this lighting. To enhance short field operations,

the C-130 is capable of using assisted takeoff (ATO) rockets. These rockets add to the aircraft's takeoff or climb capability; however, transportation and installation of ATO bottles present logistic problems (6:2-35).

Air delivery of troops, equipment and supplies is an important facet of the C-130's potential. All KC-130s are capable of day/night and all-weather air drops. This gives versatility to the transport role of the Hercules.

The long-range ability of the Hercules serves the Marine Corps' needs in many areas. VMGR squadrons will continue to support Marines through long-range missions which could include casualty evacuation from foreign combat zones or routine resupply missions.

Several KC-130 aircraft are designated as command and control aircraft. These aircraft are specially equipped with electrical power sources and antennas designed to accommodate command and control packages.

Rapid ground refueling has always been a capability of the Marine Hercules. KC-130s are well equipped to perform the mission of rapid ground refueling due to its large fuel capacity, plumbing and special high pressure/volume fuel pumps. These pumps are capable of providing a maximum of 300 gallons per minute at 40-50 pounds per square inch (6:3-3). Fuel is transferred from the KC-130 to other aircraft through rubber fuel hoses. These hoses can be configured with numerous refueling points; however, the more points, the less the fuel pressure per point. Electrical power for the aircraft fuel pumps is provided by the Hercules' engines or an external ground power source. Recently, emphasis has been placed on utilizing the ground refueling ability. It is particularly important that every Marine aircraft type is compatible to ground refueling from the KC-130. The Hercules is able to ground refuel all but a few aircraft, with both the KC-130 and the aircraft being refueled with engines running. This "hot refueling" capability expedites operations.

Flare delivery by the KC-130 provides illumination for a variety of missions. Illumination for close air support missions, helo assault, and search and rescue missions can be provided (6:3-8). Flare missions provide pinpoint illumination to areas inaccessible to artillery or motor units. The MI-45 and the LUU-2 A/B are the primary flares used by the Hercules. A MK 45 will provide 2 million candlepower of illumination for 210 seconds and the LUU-2 A/B provides 1.6 million candlepower of illumination for 300 seconds (6:3-8,11).

It can be seen that the KC-130 is a highly versatile aircraft with proven capabilities and potential. Obviously, these capabilities are limited by the ever-increasing enemy threat. This threat includes highly sophisticated surface to air weapons and

small, hand-held anti-aircraft missiles. High threat missions present real problems for the unarmed KC-130 and cannot always be accomplished without a degree of risk to the aircraft and crew. The abilities of the KC-130 tremendously outweigh its short-comings. If used advantageously while taking into account its lack of defenses, a Hercules is a valuable tool to the Marine combat commander.

Chapter Four

THE KC-130's ROLE IN MEU (SOC) OPERATIONS

Before effective use of the Hercules can be enjoyed, a close examination of its potential must be accomplished. Comparison of the missions and tasks of the MEU (SOC) and those of the VMGR squadrons clearly show an exciting compatibility. As previously stated, The KC-130 is primarily designed to support refueling operations. This capability includes airborne refueling of fixed wing fighter and attack aircraft, airborne refueling of the CH-53E helicopter, and ground refueling of all aircraft operated by the U.S. Marine Corps. Logistically, the KC-130 has the potential to enhance the MEU (SOC) commander's capability by serving as a force multiplier. As a force multiplier the Hercules gives the tactical fixed wing and rotary aircraft extended on station time, range, and stand-off distance. Utilizing the Hercules in rapid ground refueling (RGR) gives the MEU (SOC) commander the benefit of using short, unimproved airfields to refuel aircraft that do not possess air refueling capabilities. Ground refueling will give greater range to those aircraft, thereby increasing the MEU (SOC) commander's operational flexibility.

The KC-130's capability of long-range transport of equipment or personnel, combat troops, civilian and medical evacuees for the MEU (SOC) commander must be utilized. Conducting missions day or night in adverse weather conditions to conventional and unimproved airfields or through the use of air drops offers the commander excellent flexibility. Specifically, the MEU (SOC) commander can use the KC-130 to insert reconnaissance teams, move equipment or move other personnel non-transportable by helicopter. This relates directly to the MEU (SOC's) ability to conduct amphibious raids or evacuate personnel. Because of its size, speed, and range, the KC-130 is of great value in evacuations of personnel, military or noncombatants.

The Hercules possesses a unique combination of avionics equipment (radios and navigation instruments), lending itself well as a command and control platform. A limited number of aircraft also possess special antennas and power supplies designed for command and control packages. These packages consist of a van equipped with a plotting board and various UHF, VHF, FM and HF radios. Long-range precision navigational capability, extended range and long loiter time lends well to the Hercules functioning as a lead aircraft on extended missions. The command and control potential in combination with the air and

ground refueling capabilities should be clearly understood by the MEU (SOC) commander during the planning phase of all operations.

Flares are used by the KC-130 to provide illumination. In the direct illumination role, the Hercules provides illumination for night assaults, opposed or unopposed, air or ground, night close air support, search and rescue operations, or for defensive operations. Examples of direct illumination include flare drops directly over helicopter landing zones, targets, or areas of ground operations. In the indirect role flares are not dropped over the operating area but at a distance, and give indirect light for night vision goggle work or provide for a deceptive technique. Flare drops at a point other than that of the operation may confuse the enemy as to a commander's true intentions. When a surface to air threat exists, flare mission should never be attempted.

The capabilities of the KC-130 provide the MEU (SOC) commander a great deal of flexibility and latitude. Consideration must be given to the limitations of the KC-130 system. These limitations will dictate how, when, and where the commander should employ his aircraft.

Chapter Five

KC-130 SYSTEMS LIMITATIONS/RECOMMENDATIONS

The knowledge of strengths and weaknesses of one's self, his assets, and those of his opponent, are some of the keys to success. This chapter will examine the limitations and weaknesses of the KC-130 system. A major consideration of a commander is the proficiency of his aircrews to perform specific missions. An example of a specific limitation caused by the aircrew would be a crew incapable of performing a low-level mission due to the lack of proficiency. Although the KC-130 is designed to fly low, this does not necessarily mean the pilots and crew are competent at low altitude flying. Attempts to fly at low altitudes when the aircrew is not properly trained can obviously lead to an unaccomplished mission or even loss of the aircraft. This example of low-level flight proficiency applies to numerous facets of flight skills that must be performed to accomplish a mission.

To provide for aircrew proficiency and ensure completion of assigned MEU (SOC) missions, emphasis must be placed on realistic aircrew training programs. These programs must be established based upon MEU (SOC) requirements. Currently, an inadequate training program administratively exists as published in the Marine Corps Aviation Training and Readiness Manual, Volume 2. To support the full spectrum of MEU (SOC) operations, refinements and modifications are necessary to ensure that Hercules pilots are highly qualified in all aspects of KC-130 tactics. Modifications of these training programs depend directly upon the mission needs of the MEU (SOC). Training program expansion must include areas such as night vision goggle flying, low altitude parachute extraction system (LAPES) training and defensive tactics (DEFTAC). Night multi-tanker air refueling also requires the initiation of a comprehensive training program. A building block approach to training is essential. An example of this type of training is the requirement that KC-130 pilots fly several night formation flights prior to conducting multi-tanker night refueling missions. Some phases of training would have to be augmented with equipment acquisition. Equipment procurement will be addressed later.

Aircrew capabilities suffer from the programs as outlined in Navy and Marine Corps publications, but they are more often plagued by the lack of flight time allocated for training. Hercules operators feel that heavy operational commitments have negatively impacted their squadron (15:1). Statistics indicate

that only one-third of the total squadron flight time supports squadron training (16; 17). This lack of dedicated training time exemplifies the negative nature commitment flights have on squadron training. A more equitable division of flight time would dedicate 45 percent of the squadron's total flight time to squadron training (15:1). If new programs are added, more flight time must be dedicated to aircrew training.

At the present time, a limited number of KC-130 pilots are 100 percent capable or fully qualified in all missions of the aircraft as outlined in the Training and Readiness Manual, the KC-130 NATOPS manual and FMFM 5-1. Combat readiness percentage (CRP) is used as a tool to track flight crew combat readiness. CRP is computed by allocating a given number of percentage points for each qualifying skill a flight member possesses. CRP also takes into account the time interval between missions that require certain skills. Historically, VMGR squadron pilots maintain 80 percent combat readiness percentage (CRP) plus or minus 5 percent (13; 14). Aircraft commanders maintain a slightly higher CRP than co-pilots but mission capability is measured by the lowest CRP within the crew.

Aircrew training levels directly relate to the MEU (SOC) commander's capability to employ the aircraft. Due to the lack of available training time, a very small percentage of aircrews can be expected to perform specialized missions (14:1).

The Marine Hercules is getting a new tactical paint scheme, but tactical equipment procurement is questionable due to fiscal restraints. Commanders must think of how the KC-130 as a combat aircraft can be used on the modern battlefield, and stop thinking of the Hercules as an airliner. The lack of defensive equipment such as chaff or flares dictates that the Hercules only be operated in a very low-threat environment. Operations in a high threat environment could be disastrous. The lack of secure communications equipment is another ongoing problem that must be resolved by the VMGR community (10:4). The lack of secure communications equipment eliminates secure communications between the KC-130 and other special operations aircraft. Also, other equipment may be needed if more specialized missions are expected of the Hercules. Equipment such as night vision goggles must be procured to perform the full spectrum of night operations. It cannot be overemphasized that understanding aircrew training levels and the KC-130 equipment capabilities is a key to knowing the limits of the Hercules in a special operations roles.

Currently, the KC-130 is capable of performing all the previously assigned missions in a low altitude, daytime, VFR, low threat environment (6:2). Hercules crews can fly night, low altitude missions and land on unimproved limited lighted airfields, but they face certain restrictions. The KC-130 as presently equipped and aircrews as presently trained have limited night, low level mission capabilities and cannot operate from

non-lighted airfields. To expect a full range of these capabilities to exist is an unrealistic assumption that could lead to mission failures and unacceptable attrition rates. The future could look good for the KC-130 community, within five years. Equipment scheduled for procurement includes defensive electronic countermeasures equipment, night vision goggles and compatible aircraft lighting, a global positioning system, SATCOM antenna, and improved radios (12:1). Various systems packages and improved cargo handling equipment are proposed for procurement during the 1990s (12:1). However, budgetary restraints could cause deletion of some equipment procurement. In addition to the already scheduled procurements, future mission requirements may dictate the need for specialized equipment to include an inflight refueling capability for the KC-130, and night all-weather low altitude flight instrumentation. The fact is that a specialized special operations capable C-130 exists today.

A prototype special operations C-130 can be found in the United States Air Force aircraft inventory. The US Air Force MC-130 is a special operative configured C-130 which includes: terrain following radar, ground mapping radar, electronic countermeasures, high-speed, low-level aerial delivery system, ground-acquisition receiver/interrogator, inflight refueling, secure HF, VHF, VHF-FM and SATCOM radios and forward looking, infrared capabilities (9:5-6). According to Air Force doctrine, this equipment is necessary for specialized missions (9:5-6). These special missions include blacked out landings, low-level, all-weather flights, and penetrations deep behind enemy lines in a high-threat area.

Careful thought must always be given prior to procuring of new systems or equipment. It must be remembered that added technical equipment requires additional personnel to perform increased maintenance. When maintenance needs increase, so does the need for trained personnel and spare parts. The cost of training these added personnel and the procurement of specialized spare parts could be prohibitive. The increase in equipment can also lead to increased equipment failure and possible mission abort. Although obvious, these facts must be remembered when procurement programs are initiated.

An area that must be specifically addressed is that of the Air-to-Air and Ground-to-Air equipment needed to counter this threat. Although defensive equipment, to include radar detectors, chaff and flares, is scheduled for procurement in the early 1990s, in the past procurement schedules have been extended due to low priority and budgetary restraints. Budgetary priorities must include procurement of defensive equipment.

An airborne delivery system to be used in a high-threat environment should be procured. Two systems are currently available that could satisfy the airdrop requirement. The airdrop systems which lend themselves to the high-threat environments are

the low-altitude parachute extraction system (LAPES) and the low-altitude, high-speed airdrop system as now installed on the MC-130. The LAPES system is the most practical method that the Marine Corps can adopt due to the system's low cost and short installation time (15:1). The high-speed airdrop system requires major airframe modifications. Although equipment requirements represent difficulties to the special operations concept, personnel and training present other unique problems.

An approach to the training problem is the establishment of a cadre of specially trained crews who would train with the MEU (SOC) and deploy with the MEU (SOC). This approach raises many issues to include those of personnel administration, pay and leave, TAD funding, and actual locations of the attached KC-130s. The fact that the Hercules cannot operate from ships as does the MEU (SOC) presents problems of VMGR squadron responsibilities associated with geographical locations of the MEU (SOC). If a MEU (SOC) originates from the continental US and sails to the western Pacific, who is responsible for the support of the MEU (SOC) VMGR-352 on the West Coast or VMGR-152 in Okinawa? Dedication of two aircraft per MEU (SOC) has been suggested but this presents a significant problem because of geographical overlaps into a squadron's areas of responsibilities. It is possible that both VMGR-152 and VMGR-352 both allocate two aircraft for a specific MEU (SOC). When a 50 percent aircraft backup rate is added to the above numbers, we come up with potentially six KC-130s being allotted to a single MEU (SOC). The MEU (SOC) must be task organized and assets allotted. These KC-130 assets should be in direct support of the MEU (SOC) administratively, operationally and logistically.

As previously addressed, aircrew training requires considerable attention. MAWTS-1 must work closely with HQMC, the MEU commander and the VMGR squadrons in order to establish realistic training programs that will facilitate the KC-130 aircrew accomplishment of the MEU (SOC) mission. Moreover, all the commanders must fight to ensure that training flight hours are available.

The lack of trained ground personnel to survey, test, and prepare unimproved airfields needs to be addressed. Where will these people come from? The US Air Force has Combat Control Teams to satisfy its requirements. Unlike the US Air Force, the Marine Corps does not have these teams. Training of special teams must commence immediately. The MEU (SOC) must provide personnel to attend Air Force Combat Control Team School. Those personnel should work closely with KC-130s during pre-deployment training, and deploy with the KC-130.

These problems are by far not all that exist and new ones will be identified in the future. As more experience is gained in the area of special operations, program refinement can be accomplished. Particular attention to the economical utilization of our assets can be made through careful, well-planned programs.

Chapter Six

CONCLUSIONS

In conclusion, it is evident the Marine Hercules with its aircrew is potentially a valuable asset to the MEU (SOC) commander. However, the MEU (SOC) commanders and VMGR commanders must work closely together to establish viable tasks and solve mutual problems. Total understanding of the KC-130 and aircrew capabilities will permit the commander to effectively and efficiently employ this aircraft. Concerted efforts must be made to procure needed equipment and push for realistic training programs. Wing commanders must give dedicated training time to Hercules squadrons. Likewise, squadron commanders must emphasize quality tactical training. Because of financial restrictions and the fact that the MEU (SOC) may become involved in very specialized missions, it cannot be expected that the Hercules as equipped can provide all the support that may be required. If the Marine Corps seriously plans to employ KC-130s in a special operations role, thought should be given to the procurement of a limited number of the Air Force's Combat Talon MC-130s.

The Marine Corps is moving in the right direction with its emphasis on special operations capabilities and the increased awareness of special operations within the VMGR squadrons. What are the areas of responsibility, levels of training and required equipment procurements? These are questions that must be answered. Through hard work, coordinated efforts and sound thinking, lessons regarding special operations will not be learned the hard way!

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Contemporary
Historical
Evaluation of
Combat
Operations

NIGHT INTERDICTION IN SOUTHEAST ASIA

9 SEP 66

HQ PACAF

Directorate, Tactical Evaluation
CHECO Division

Prepared by: Captain Melvin F. Porter

S.E. Asia Team

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NIGHT INTERDICTION IN SOUTHEAST ASIA

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FOREWORD

The following report has been prepared to illustrate the growth of the USAF night interdiction program in Southeast Asia from its inception in January 1965 through June 1966. The initial problems, the rules and restraints, the tactics and techniques that have evolved, and the increase in effectiveness and weight of effort are discussed. Through the gradual easing of restraints, the perfection of techniques and the introduction of new and improved weapon systems, the impact of the night interdiction role within the overall interdiction program for Southeast Asia is set forth.

NIGHT INTERDICTION IN SOUTHEAST ASIA

I. BACKGROUND

In accord with the overall emphasis on interdiction in Southeast Asia, the concept of night interdiction was under serious consideration very early in 1965. The BARREL ROLL program of tactical air strikes in Laos had begun in mid-December 1964, and on 8 January 1965, the Joint Chiefs of Staff requested comments and recommendations as to the best way to expand both day and night air interdiction in Laos with minimum risk to U.S. aircraft. Although both day and night operations were discussed, it appeared that JCS desired these comments to be primarily directed at methods of improving night interdiction operations. In response to the JCS request, CINCPACAF pointed out that the armed reconnaissance program had encountered several problems that made interdiction difficult.[1/] He listed some of the problems as:

a. Unfavorable weather.

b. Sources of supply are hidden in sanctuaries.

c. Jungle cover.

d. Unimproved LOC's.

e. Darkness.

f. Rugged terrain.

An interdiction program, to be effective, must be responsive to the tactical situation as regards routes flown, frequency and timing of missions and target selection. It must also be continuous, comprehensive, coordinated, and with the flexibility required for rapid response to Pathet Lao/Viet Minh tactics and pattern of operations.

It was further felt that as of the beginning of 1965 this level of responsiveness had not been reached, and that the above factors should be considered in reviewing results obtained up to early January 1965.

CINCPACAF felt that night route reconnaissance missions, in conjunction with day armed recce mission, YANKEE TEAM (photographic reconnaissance in Laos), and Royal Laotian Air Force operations, were desirable to provide a balanced day/night program to maintain constant pressure on enemy LOC's. Accomplishment of armed recce, in his view, could be made by relatively long endurance aircraft which could carry their own flare capability. Provisions in the program should include the use of cargo flare aircraft and shorter endurance aircraft to either accompany the flare aircraft, or to be on call as the tactical situation dictated. Further the night detection program could be improved through the use of Infra-Red, or Side Looking Aerial Radar (IR/SLAR) with cockpit readout aircraft to guide flare aircraft to suspected targets. He pointed out that both systems were available in limited degree in-country and could be employed as operational capability permitted.

He felt that the idea of using U.S. air against targets reported by roadwatch teams was worthy of trial, provided that the necessary flexibility and authority could be secured for the operational commander. However, identification would continue to present a major problem and certain administrative and operational problems remained to be solved. [2/]

With reference to AAA positions, CINCPACAF felt that while attack on a preplanned basis might be desirable, such a target would be difficult to identify under flare illumination. Since the Pathet Lao had on occasion moved such weapons from prepared sites into forests and back again, it was believed that, from the military standpoint, the maximum return would be obtained through a program of heavy day strikes on many positions within a short time frame. This tactic hopefully would inflict severe damage before the enemy could counter through dispersal, camouflage or the introduction of more sophisticated weapons and thus raise the price of attack.

Night strike targets, in his opinion, had to be clearly identifiable, with an absolute minimum chance of mis-identification. He concurred in the use of time delay fuses, tire puncturing tetrahedrons, the MLU-10B aerial-laid land mines, and other similar type weapons. CINCPACAF felt that the U.S. had the resources and capability to conduct an effective interdiction program in Laos, but that it must be comprehensive, not piecemeal. He stated:[3]

> "...To be effective in the present environment in Laos, the interdiction program must provide for frequent coverage of important routes and targets and should be capable of immediate flexible reaction to the day-to-day intelligence and operational factors."

After learning that the first night BARREL ROLL mission within Laos was scheduled for the period of 4 - 10 January, 1965, the Commander of the 13th Air Force, Major General Sam Maddux recommended that an

immediate night armed recce training program for F-105's be set up and that flight could later be exchanged with the flight presently at Korat. In addition, he said he intended to include F-100 training (Takhli squadron) along with the current B-57 interdiction training program in order to increase F-100 pilot capabilities.[4]

Second Air Division proposed to use NIGHT OWL (TAC-trained night-proficient F-100 crews) pilots from Da Nang for the USAF's first out-of-country night mission, and in this General Maddux agreed. However, he did believe that the mission timing might be premature, and suggested a long hard look at things to determine if the capability existed to produce the desired results. He felt it might be wiser to run a few night practice missions, under flares, prior to an actual mission. The 405th Tactical Fighter Wing's B-57 crews, already in night training in the Philippines, were coming along well, Maddux mentioned, but until Phase II training had been accomplished over land and with live ordnance he did feel that the first USAF night effort, when flown, should be with NIGHT OWL.

II. THE TANG VAI INCIDENT

Certain of the items mentioned by CINCPACAF, and by Generals Maddux and Moore, were highlighted before the Air Force flew its first night BARREL ROLL mission. Among these were the problem areas of night navigation and target mis-identification, which almost resulted in the cancellation of the night interdiction program before it was underway. On the night of 15 January 1965, the U.S. Navy inadvertently bombed a friendly Laotian village, Ban Tang Vai,

located at 16°25' North and 105°39' East. After an investigation, CINCPACFLT made a report of the bombing.[5] This showed that six A-1H's (divided into two flights of three - with one aircraft of each flight being a flareship) did bomb the village. The report indicated that the leader became separated from his flare aircraft when the latter experienced a partial radio failure. While looking for the flare plane, the flight leader then lost contact with Route 23, a heavily jungled road, and then inadvertently flew some ten to fifteen miles south. Abandoning his search, he turned back toward Route 23. At this time, he saw a fire on the ground which he thought might have been the flare aircraft which could have crashed. His wingman dropped lower to identify the fire and found it to be a burning house. He also reported seeing lights of three trucks moving on a road to the northwest of the fire. The flight leader then decided to attack and each of the two aircraft dropped two 250-pound bombs in the area. At the time of attack, the flight leader was uncertain of his exact position, believing himself to be over hostile territory. Actually, he was some twelve miles west of where he thought he was - over the friendly village of Tang Vai.

At this point, another incident added to the already mixed-up situation. The ground investigation was conducted by Captain Shinkle, USAF, from the office of AIRA, Vientiane. Captain Shinkle picked up fragments of a 750-pound bomb, a type not carried by

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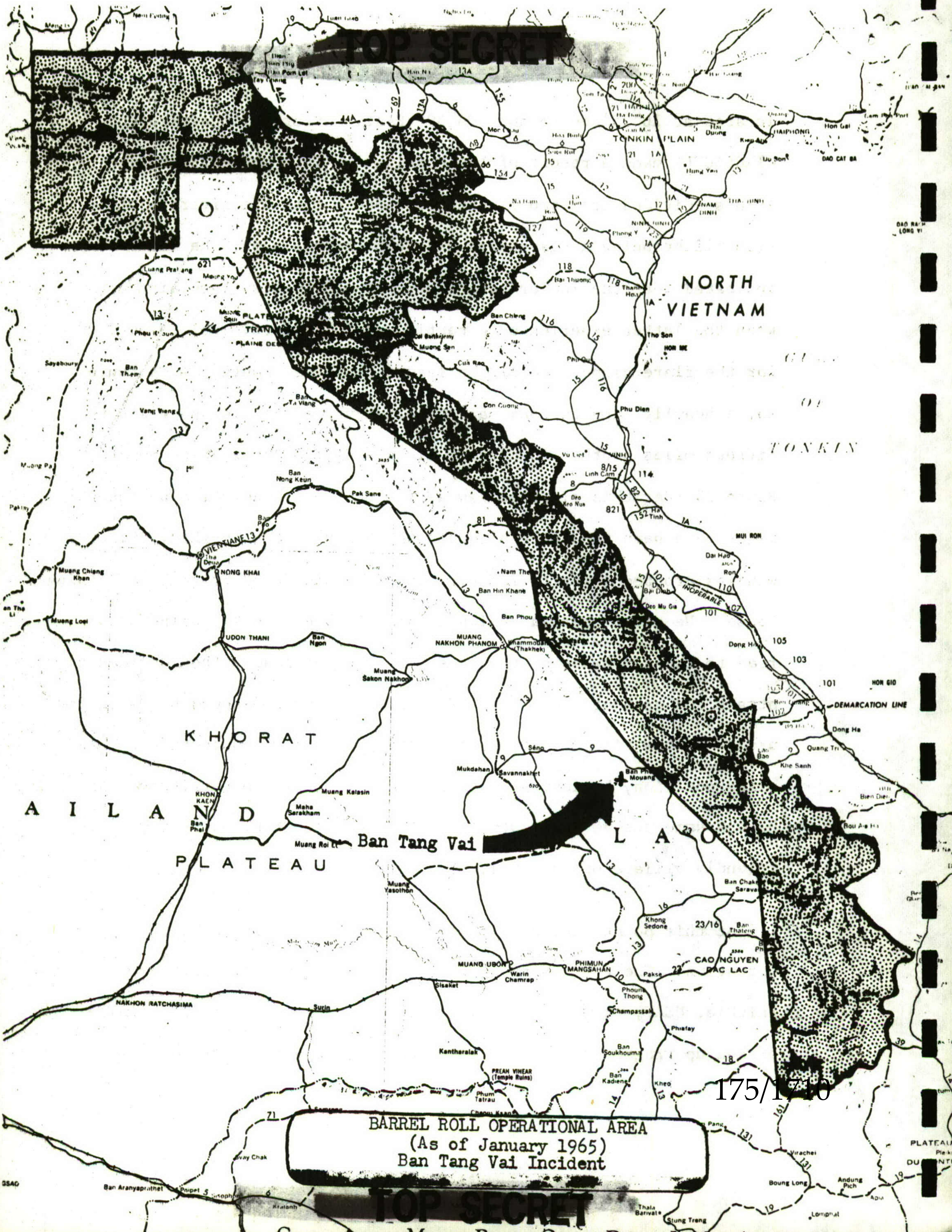

BARREL ROLL OPERATIONAL AREA
(As of January 1965)
Ban Tang Vai Incident

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the Navy planes. The Navy pilots also reported that, just before they attacked, an unidentified high speed aircraft was sighted in the general vicinity. They had seen unidentified flares and heard English language radio transmissions concerning the flares. Further, the large fire which attracted the flight leaders attention was not the result of the Navy attacks. Since no Air Force aircraft had been fragged into BARREL ROLL and the Laotian T-28's could not carry 750-pound bombs, the story was never fully clarified.

Four Laotian civilians were slightly wounded in the attacks and one Laotian soldier was evacuated for hospital treatment. Five houses and seven rice granaries were damaged, at an estimated damage cost of $2000 to $4500. CINCPACFLT said there was substantial doubt that the injuries and damage to property were the result of the Navy A-1H attacks although, admittedly, the A-1H flight leader exercised poor judgment in attacking a target when not positive of his position.

General Thao Ma, Commander of the Royal Laotian Air Force (RLAF) was infuriated. At first he thought that some of his political enemies in Laos might have duped the U.S. into bombing a friendly village to help destroy his political strength.[6] All BARREL ROLL missions were immediately suspended and an American team was hurried to the village to render aid.

Ambassador Sullivan made a special trip to Savannakhet the morning of 18 January to personally discuss with General Ma the consequences

of the Tang Vai incident.[7] Ma accepted the personal regrets of Secretary Rusk and Admiral Moorer graciously but without enthusiasm. The general continued to harbor suspicion that Vientiane politics may have had something to do with the affair and that the U.S. might somehow have been made an unwitting dupe by elements of the Lao political scene. The Ambassador attempted to convince him to the contrary and said that the U.S. was conducting a formal investigation, the results of which would be made available to Ma.

Ma indicated that the material damage to the village was of less concern than the psychological effect. He said that the villagers first suspected "Russian" retaliation for their cooperation with FAR (Force Armee Royale) and Royal Laotian Government officials. The villagers apparently became confused when told that the incident was the result of an American error. He, therefore, welcomed the Ambassador's prompt offer of relief and assistance. Ma's reaction of suspicion was illustrative of the general aura of mistrust and wariness displayed by the military and political leaders in the Southeast Asia sphere.

As for continuation of future BARREL ROLL missions, Ma agreed that the operation could be resumed, both day and night, but insisted that - at least in the region south of Route 9 - they be confined to the area east of Muong Phine. This meant that Route 23, from that point south, would be the exclusive preserve of the RLAF. It was also established that night BARREL ROLL operations would be conducted without secondary targets and, for an extended period, any ordnance not expended on route reconnaissance

must be jettisoned in the sea or returned to base. One of Ma's strongest provisos for resumption of BARREL ROLL operations stated that targets of opportunity by definition should be limited to vehicle and troop movements observed on or near roads. He made a special point that campfires were not to be considered evidence of enemy presence. It was far more likely, he thought, that campfires would indicate friendly villagers or friendly forces rather than enemy.

The Ambassador to Laos had been instructed by Washington to tell the Laotians the results of the investigation at Tang Vai, but he decided it would not be prudent to release all the information in light of the discovery of the strange bomb fragments.[8/] In his oral reports to General Ma and to the Laotian Premier, Prince Souvanna Phouma, he limited his remarks to the Navy episode, particularly since the furor immediately attending the event subsided rapidly following his offer of American assistance.[9/] Souvanna Phouma displayed no undue preoccupation with the incident, although he did express gratitude for the U.S. aid to the victims. From his contact with the Prince and with General Ma, Ambassador Sullivan felt that the early resumption of BARREL ROLL was assured, albeit under revised ground roles. He was proved correct when authority for BARREL ROLL operations was renewed on 19 January 1965.

III. RULES & RESTRICTIONS

The rules of engagement in BARREL ROLL, from the military standpoint, were already inhibited by strong constraints. From the beginning of these operations, there was a requirement for a "sterile" period

between missions. These periods were initially of three days and were intended to preclude giving any impression of a sudden escalation of air operations in Laos. The sterile period was later reduced to 48 hours. However, there remained a specified time block, usually a week, for the execution of two missions. Weather and other factors sometimes caused repeated deferral of missions and, as the end of a BARREL ROLL period approached, there was considerable uncertainty at nearly all command levels regarding the authority to execute a particular mission.[10/]

On 9 January 1965, a decision by the JCS was made not to set an expiration date for the execution of a specific mission, aborted because of weather or other operational reasons. At the time, it was announced that the deferred missions would constitute a "bank" of approved tasks which could be executed when feasible.[11/] This improved the flexibility but other rules continued to restrain the operations.

Targeting took an inordinately long time because many agencies were involved and final approval was vested within the State Department and Department of Defense. It took at least two weeks, and usually much longer, for a preplanned target or for an armed route recce section to be approved. Pilots and commanders did not have the choice of which direction they would fly a given armed recce. Flights were not allowed within two miles of the North Vietnamese Border on armed reconnaissance missions. Ordnance was the option

of the operational commander except that napalm would not be used. To the framework of these constraints were added General Ma's latest restrictions discussed previously.

IV. TARGET ACQUISITION

The problem of target mis-identification, occuring as it did at the outset of the program has continued despite efforts to improve the situation. The Chief of Staff, USAF, sent the following message to CINCPACAF, and which was forwarded to Generals Moore and Maddux: [12/]

> "As a result of the unfortunate results of PACFLT BARREL ROLL mission under 10 (Tang Vai incident), the air staff has reviewed the problem of night target acquisition. The problem is a formidable one, however, some suggestions which might assist Air Force units to positively identify fixed targets and recce routes in Laos are offered for your consideration: (1) The Udorn and Nakhon Phanom radars can be used to position aircraft at altitude over designated routes or targets; (2) Prestrike recce of assigned routes and targets within preceding 12 hours will assist pilots; (3) Use Laos-experienced recce pilots as pathfinders in flare and/or BDA aircraft; (4) Assign F-105's for night missions so as to use Doppler navigation system; (5) Use Da Nang, Udorn, and Korat TACAN to fix positions. Undoubtedly, you have also studied the problem of night target acquisition."

The problem also existed with regard to secondary targets for night strikes. General Ma had stipulated "no secondary targets" following Tang Vai. PACAF had requested comments from Generals Maddux and Moore in order to provide response to JCS regarding such targets for night operations in Laos; JCS definitely wanted secondary targets for several reasons. [13/]

They pointed out that these armed recce missions, at night, would find targets of opportunity only by random chance and at odds less than even. These aircraft, returning to carriers and to the crowded Southeast Asia air bases with unexpended ordnance aboard presented unjustifiable hazards. Jettison of ordnance at sea would endanger friendly craft unless great surveillance control was established; would be wasteful and would impose undue operational uncertainties. Assignment of secondary targets would also minimize the counter-productive aspects of missions flown with no targets attacked, the futility of which would be clearly evident to the enemy.

PACAF stressed the need to provide targets which would permit ease of recognition, a relationship to surrounding recognizable terrain features and separation from friendly areas.

Thirteenth Air Force brought out the possibility of using SHORAN to pinpoint secondary targets.[14/] Admitting that the night acquisition of these targets was difficult and touchy at best, 13th Air Force noted that, though Doppler, TACAN and GCI were excellent aids, once the aircraft was beyond effective radio and radar coverage, the TACAN and GCI were lost. The B-57 had the SHORAN capability, 13th said, and could provide an excellent means of pinpointing secondaries in the event recce proved unrewarding. Although there were no SHORAN transmitters in Southeast Asia, 13th believed some deactivated units were positioned in Japan. The bid was made for a coordinated attack utilizing the B-57-SHORAN to pinpoint the target, a C-130 to drop the flares, and fighter aircraft making the strike.

In a memo from Lt Colonel Coombs, Chief of Reconnaissance for 2AD, to Colonel Harold Price, 2AD Director of Operations, the above rationale was questioned.[15] Colonel Coombs admitted the accuracy of the SHORAN system when the beacon sites were correctly surveyed and the target sites were correctly plotted, but doubted that the latter was the case in Southeast Asia. In any event, this question amounted to, "Why have the B-57 pinpoint the target for another aircraft?" The C-130 would have to fly in formation with the B-57 and drop on his signal. Using the B-57 for the whole job, was his point; locate the target, drop the flares, and hit the target by itself, instead of involving the other types of aircraft.

V. NIGHT INTERDICTION & RECONNAISSANCE

PACAF had shown considerable interest in the RB-57's PATRICIA LYNN aircraft (Infra-Red reconnaissance) and suggested it be tested on the first night BARREL ROLL effort. It was felt that if infra-red could resolve moving targets, there would be measurable gains through the element of surprise.[16] General Moore, however, had the authority for final decision as to which aircraft would make the strikes, and his choice lay in the F-100, with qualified NIGHT OWL pilots.[17] He was convinced that the RB-57 equipment did not presently have the capability to identify vehicles.

Other factors listed as pertinent to his selection of the F-100 were:[18]

a. (F-100) unit only contingency force trained for night delivery and crews exceptionally well qualified.

b. Crews have flown over Laos and are familiar with terrain. A-1E aircrews totally unfamiliar with terrain and have flown night strikes in the flat delta areas only.

c. Selected crews represent years of tactical experience in night delivery.

d. Although F-105 better airframe, crews have no experience in night delivery.

e. B-57 crews still in training. At this time do not consider them capable.

f. Consider this an excellent opportunity to prove USAF jet aircraft can meet mission requirements, day and night.

The first USAF night strike effort in Laos was to be BARREL ROLL 7 scheduled for 4 - 10 January, 1965, Aircraft, although actually launched on 9 January for the mission, found the target area weathered-in so returned to base. The mission was rescheduled and flown on 22 January with a C-130 flareship, Blind Bat One, and with F-100's - call signs Manor 11 through 14 - as strike aircraft. The OPREP 4 (mission summary) reported:[19/]

> "...The rendezvous with flareship was made as planned at 1425Z (2225H). Prior to recce start point considerable activity and ground lights noted in the eastern edge of the PDJ (Plaine des Jarres). Positive sightings of vehicular traffic were observed west and southwest of Nong Het between estimated coordinates UG 1453 and UG 2862. Recce was started at Nong Het 1435Z and continued to a point east of Ban Ken with no sightings except for occasional campfires. East of Ban Ken Bridge lights were sighted by Blind Bat 1. Flares were dropped

> and a section of Route 7 lighted. Manor 11 and 12 each made passes under the flares and no vehicular traffic or activity was noted. The only lights found were in a small village on the south side of road. Estimated location was UG 6865. Malfunction of the UHF receiver of Blind Bat 1 made join-up difficult and restricted operations throughout the remainder of the flight. At UG 7767 a 6-8 tenths undercast started and continued through to Nong Het. Flares were dropped using radar positioning in the Nong Het area but positive ground position was not determined due to ground cover. Small sections of ground visible through breaks in the clouds indicate approximate flaredrop point at UG 9675. Manor 11-14 withdrew with minimum fuel at 1532Z (2332H). Refueling was accomplished and all aircraft recovered at Da Nang. Although no targets were found, it is felt that this mission proved night armed reconnaissance with flares to be both feasible and workable."

Although this first night operation by the USAF outside South Vietnam was not the dramatic success that had been hoped, it did show that the basic tools for a night interdiction effort did exist, as PACAF outlined in a later message to CSAF.[20/]

> "...The PACAF operational concept for night non-nuclear interdiction involves strikes by fighters and B-57's delivering munitions on targets illuminated by flares. At the present time, target illumination is provided by C-130 type aircraft dropping flares or by tactical fighters/bombers utilizing a self-contained flare capability (LAU-10/SUU-25 or internal, in B-57's). In addition, the C-130 aircraft acts as pathfinder, and airborne FAC as necessary. This concept permits employment of various planning aspects and provides a greater degree of operational flexibility to the commander concerned. Target acquisition will be accomplished visually, by artificial light, or by predetermined radar identification features. With the exception of higher than normal recovery altitudes or ordnance delivery "run-ins" and a reduction in the number of passes available, the techniques to be used for night ordnance deliveries under flares vary little from those used during the day. The

> methods or modes to be utilized in delivering ordnance under flares that appear most feasible are low-level bombing, low-angle bombing, rocketry and strafing. It is believed that initial accuracies will not equal those attained under daylight conditions; however, as experience is gained, night accuracies may equal daylight accuracies."

Although they are often equated, accuracy is not necessarily synonymous with success. In this case, the artificial constraints made accuracy an absolute necessity and a successful night interdiction program hard to achieve. An example of a directive which imposed unnecessary restrictions on the tactical commander was brought up by 2AD.[21] BARREL ROLL 15 was a night armed route recce mission that had been directed to fly its route from west to east in order to avoid overflying North Vietnam. The weather conditions, when the mission was actually flown, favored initiation of the mission at the east end, where the weather was clear, proceeding westward where weather over the last third of the route was broken. These broken clouds made the exact point on the road at which to begin the recce difficult to locate. In 2AD's view, such factors as weather, AAA defense and fuel are variables which prohibit prescribing tactics to be used several days ahead. Tactics are best determined, 2AD said, by a study of many factors including latest intelligence, the latest weather, and the views of the pilots who are familiar with the target or the road, as the case may be. Second Air Division made the point that, if fear of DRV border violation was a matter of concern in this particular case, the possibility of such would be less by navigating to the point (the two mile limit) at medium to high altitude

with radar assistance than by proceeding toward the border at six and eight thousand feet without radar. MACV concurred that such constraints unnecessarily restricted the tactical commander's ability to accomplish his mission, and emphasized necessity for tactical flexibility. MACV recommended that, in the future, all such restraints be closely monitored to ensure that the tactical commander is afforded maximum flexibility.

CINCPACAF passed this to JCS along with his own plea for greater flexibility in the field and, in response, (beginning 9 February) the phrase, "direction of flight on armed recce at your discretion" began to appear in the BARREL ROLL planning messages.[22]

Being more or less in its infancy, night air interdiction naturally lent itself to difference of opinion as to which tactics and what aircraft should be used. The Navy appeared to be satisfied with its A-1H's, using organic flare carrying capability. The Commander of 2AD, Major General Joseph H. Moore believed that the C-123's, already proved in-country and flown by night-experienced flare crews, were fine for that role. CINCPACAF and 13th AF leaned strongly toward the C-130 as a flare aircraft. CINCPACAF indicated he wanted C-130's to conduct training, on an opportune basis in South Vietnam, to develop crew proficiency in flare-drops.[23] He pointed out the probability of increasing the night armed recce mission in Laos, with concomitant expansion of flare delivery. Because of the C-130's better navigational equipment, range, loiter time, and speed, he felt it offered significant operational advantages over the C-123.

Fifth Air Force, concerned over the C-130's in that environment, voiced a strong request to CINCPACAF to consider use of ECM support during the night operations.[24] 5AF pointed out the vulnerability of wet-wing cargo aircraft to directed anti-aircraft fire, especially at the altitudes from which they would be dropping flares in Laos. Admitting that Elint had no confirmed sightings of gunlaying radars in Laos, the extreme mobility of the "Fire Can" radar (which had been reported in Laos, but not confirmed), coupled with the existing concentrations of AAA there, generated a fair probability of encountering accurate night fire. Fifth Air Force thought it worthwhile to mention that QRC-160-1 ECM pods were in their inventory and that the RF-101 carrying these pods would comprise an excellent ECM package capable of severely degrading "Fire Can" radars within a 50 nautical mile radius.

The concept of night armed road reconnaissance using the C-130 aircraft as a flareship pointed up a requirement for radar photo strip coverage of pertinent areas. The 315th Air Division, "owners" of the C-130's involved, brought out that the problem of target acquisition becomes great when roads are darktop, winding and narrow and the night may be moonless.[25] The idea of identifying and striking moving vehicles after spotting lights on the road was questioned since it was believed that vehicles would simply travel with lights blacked out. A new tactic which provided for lighting up portions of a road, for the purpose of seeking out convoys/vehicles on a "catch as catch can" basis, was suggested by the 315th Air Division. If the suggestion were adopted

(random drops on known LOC's), then the next problem would be that of locating the road in order to provide effective illumination. The 315th felt that radar photo strips of the objective areas would greatly enhance navigational capability and, in turn, would result in a more effective strike mission. The concept was that initial flaredrops could be made by radar positioning, in proximity to the road, with subsequent refinement based on the results of the initial drop.[26/]

This was one of many suggestions designed to contribute to the sophistication and effectiveness of night efforts (such as the PATRICIA LYNN program and the QRC-160-1 pods), but both real sophistication and true effectiveness were long in coming. This is not to say that there were not effective missions. One typically effective night armed reconnaissance mission took place on 23 February 1965. This was BARREL ROLL 24 and was reported in a supplemental OP-4 Wrap Up Report:[27/]

> "On 23 Feb 65 a flight of six F-100's (two airborne spares) launched (the acft were from the 613th TFS at Da Nang, RVN) at 1125Z to fly night armed recce against Route Seven, Laos. Mission number was BR 6824 - call sign Tiger 11 through Tiger 16. Tiger 11-14 refueled with Bear 1 and 2 as scheduled. Flight departed refueling area and joined up with Panther 51 and Blind Bat 1 at rndz point. Blind Bat 1 then departed on course for the road recce. At UG 4374 the first flares were dropped and 4 or 5 vehicles were sighted on the road. Tiger 11 and 12 made the first passes and CBU was dropped where the vehicles were sighted. Two or three fires were started, but no more vehicles were sighted. Flight proceeded on down course to UG 5868 where Blind Bat 1 dropped more flares. In this area 10 to 12 vehicles were sighted on the road and Tiger 11 and 12 expended all their CBU in the area. At this point Tiger 13 and 14 took the lead and made one pass each on this target. In this area flak was encountered. The bursts were going off 12-13 thousand

> feet in a straight line, one to two seconds apart. Automatic weapons fire was also encountered but not effective. At UG 7667 flares were dropped at 1246Z and Tiger 13 and 14 made one pass each. Several fires were started. At UG 9365 Tiger 13 and 14 expended the rest of their ordnance and the recce was terminated at this point. Flight departed the area at 1310Z and landed at 1421Z. The weather in the whole target area was clear, with visibility 4 to 5 miles in haze except for the last five miles which had broken clouds in the hills."

Any lack of effectiveness in the program did not appear to lie intrinsically in the mission pilots' capabilities, but more within the framework of the program. It was applied piecemeal and hamstrung by the many political considerations, which were necessary at that time. But the difficulties in putting together a cohesive interdiction program, night or day, are apparent in the following BARREL ROLL OPS Order:[28/]

Operations Order for BR

> SITUATION: PACOM forces will conduct designated U.S. Armed Reconnaissance and Interdiction air strikes against infiltration routes and facilities in Laos north of Nape Pass.
>
> MISSION: Conduct air operations along selected routes and/or against prebriefed targets in northern Laos in accordance with guidance contained this operation order for purpose of disrupting PL/VM logistics flow.
>
> EXECUTION: COMUSMACV and CINCPACFLT will conduct missions as assigned by CINCPAC utilizing numbers of aircraft as appropriate for each mission. Type aircraft will be at option of operational commander and armed with optimum unclassified ordnance for target to be attacked, excluding repeat excluding napalm. Support aircraft authorized as appropriate weather and flare aircraft will operate so as to minimize risk from ground fire. BDA recce may be escorted

> and retaliatory fire by escorts is authorized. BDA recce missions may be conducted as required until successful BDA photography is obtained. Prestrike recce by YT authorized if required. Direction of flight on armed recce route is at discretion of operational commander. Targets for armed recce will be PL/VM targets of opportunity which are defined as military vehicular and troop movements and active AA guns (manned or unmanned) spotted on or near roads designated for armed recce mission being flown. Campfires and civilian habitations will not be attacked. Fixed installations will be struck only in connection with attacks on clearly identified military convoys and military personnel; or when prebriefed as primary or secondary interdiction target. Under no circumstances is ordnance to be expended in Sam Neua Town, Khang Kay, or Xieng Khouang even in response to HOSTILE FIRE. Individual mission aircraft will avoid areas (known) of heavy AA concentration and will not approach NVN border closer than two miles, unless directed differently in execute instructions. CINCPAC mission assignment message will designate effective date for execution of approved missions. Once approved there is no cut off date upon which any given mission becomes invalid for execution. Approved missions may be executed in whatever sequence prescribed by COMUSMACV in coordination with CINCPACFLT. Unless otherwise authorized only one armed recce type BR mission may be conducted during any one calendar day. Barrel Roll missions to create choke points or to periodically reseed choke points are not included in this category and may be flown without restriction as to time between these and other approved BR missions, except that each choke point in BR geographical area will not be reseeded more often than every fourth day.

Add to this state of restraint, the oddities - Thai-based aircraft could overfly Laos to strike in North Vietnam (after 7 February 65) but were not authorized to strike in Laos, and still have never been authorized to strike in South Vietnam. Navy aircraft, on the other hand, were authorized to strike in Laos, but could not fly over North Vietnam to get there. Most of these things were political considerations brought

about by the often tenuous working relationships with the heads of state of South Vietnam, Laos, and Thailand, and the necessity to "go along with, or get out" when it came to supporting their positions. As a political dictate this was understandable; as a military stricture, it was extremely confining.

It was patently impossible to carry on an effective night interdiction program using one mission every two days to interdict an area roughly the combined size of New York and Pennsylvania, (Laos: 91,500 sq. mi. - New York/Pennsylvania: 94,909 sq. mi.), heavily jungled and interlaced with foot paths.

VI. BARREL ROLL/STEEL TIGER

With agonizing slowness the situation eased. The U. S. Ambassador to Thailand received and forwarded permission for U.S. Thai-based aircraft to be used on BR Four Delta on 7 April 1965 and soon thereafter Thai-based aircraft were performing strikes as a matter of course.[29/] Another move which tended to brighten the picture was the separation of BARREL ROLL into two programs on 3 April 1965.[30/] As of that date, the JCS directed that air operations in Laos against routes and targets in the Laotian Panhandle, associated with infiltration into SVN, would be considered a separate program identified as STEEL TIGER. This was primarily in the area south of Ban Nape Pass and included the "Ho Chi Minh Trail." The northern section would remain BARREL ROLL and here the interdiction and other operations would be mainly in support of FAR/Neutralist forces of Royal Laotian Government. This had the effect

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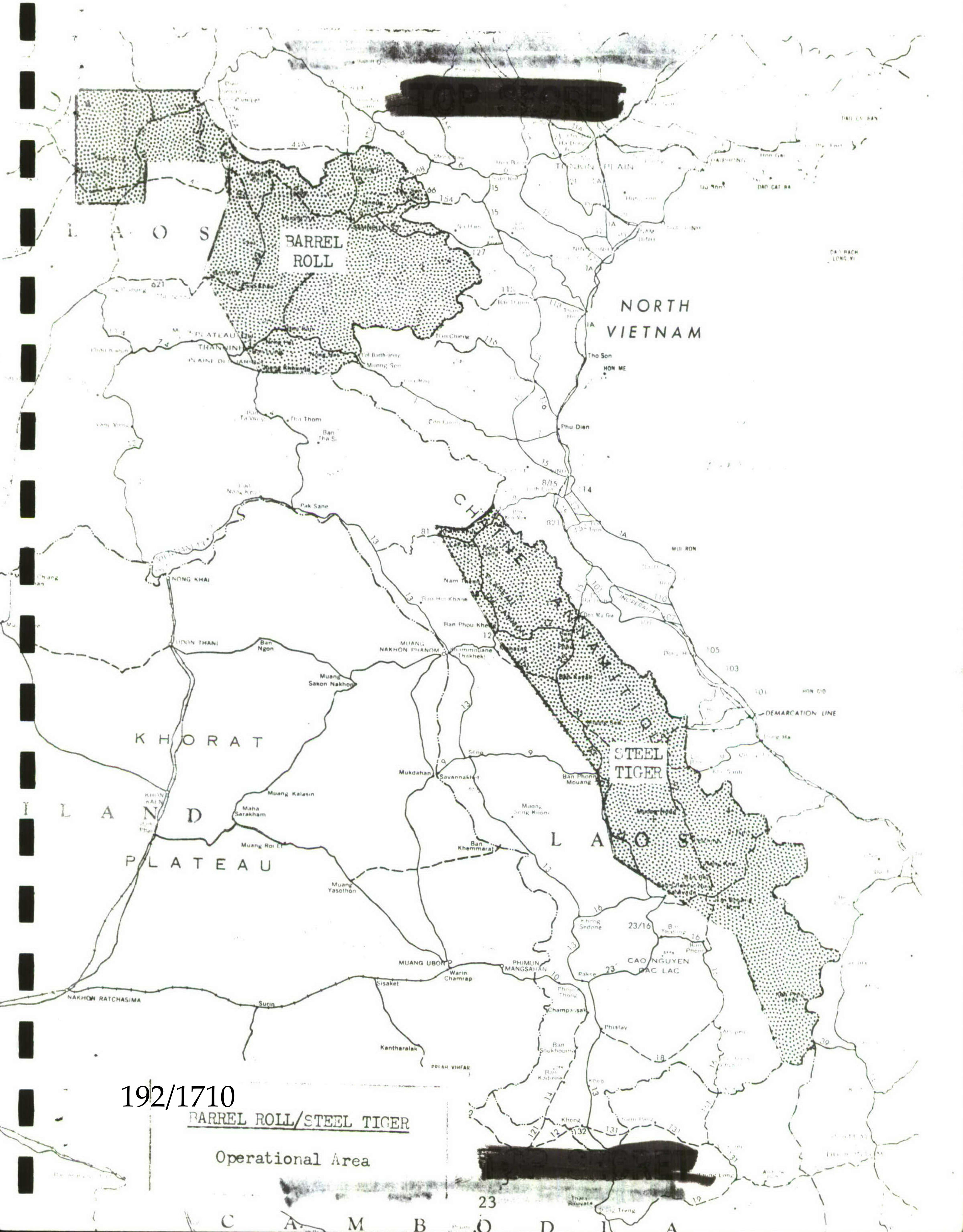

BARREL ROLL/STEEL TIGER

Operational Area

[redacted]

of increasing the number of missions, both day and night.

The 8th Tactical Fighter Wing deployed its first squadron of 18 F-4C's of the 45th Tac Fighter Squadron into Ubon, Thailand on 7 April 1965. This Wing became the workhorse unit for night operations in Laos and North Vietnam in the succeeding months. The sister squadron to the 45th TFS was to bed down at Ubon by 25 June.

Even with this increase in available strike resources, the night interdiction effort was creating no great dent in the infiltration activities. Slowly the amount of sorties was climbing, but as of 5 April a total of only 16 night armed recce missions had been flown outside South Vietnam. Of these, but six had acquired and attacked targets. Significantly, however, there were 26 day armed reconnaissance missions and <u>none</u> had achieved any sightings of moving target destruction. Two points appeared to be clear; the enemy <u>was</u> hiding out during the daylight hours, and there was significant promise in the night effort if it could be expanded into a realistic program. Such a program began to emerge with the gradual lifting of the mandatory "sterile" period between strikes, the use of Thai-based aircraft, numbers of strike aircraft per mission determined by the operational commander, and the use of napalm when approved by the American Embassy at Vietiane. STEEL TIGER's entrance into the picture brought with it the promise of permission to cover major routes with a nightly mission and the ability to strike validated secondary targets, if the armed route recce was unsuccessful.

Through 22 July 1965 thirty-one percent of the BARREL ROLL/STEEL TIGER missions had been flown at night, yet 64 percent of significant sightings had been made at night, which would make the night effort roughly twice as productive with half the effort. A welcome adjunct to night operations was the relative safety against enemy defenses - 11 USAF aircraft had been hit and four lost in day armed reconnaissance; no aircraft were hit or lost in the night armed recce. Nonetheless, the total effort and the percentage of night effort remained low through most of 1965. For example, from 6 August through 2 September there were no USAF night strikes in Laos or in the ROLLING THUNDER program in North Vietnam. The percentage of night effort, instead of going up, actually dropped. However, basic operations orders for ROLLING THUNDER for May and June 1965 both stipulated that armed reconnaissance would be conducted day and night, with emphasis on the latter.[31/] Of 669 strike sorties flown in Laos between 1-14 October 1965, only 18 were night sorties. In ROLLING THUNDER, USAF flew five missions, all with the B-57/C-130 teams. Through the last two weeks of October the USAF was still allocating only 3 or 4 percent of its sorties to night operations in ROLLING THUNDER but, during the first two weeks of November, this figure rose to 14 percent. The B-57/C-130 NIGHT WIND operations had largely supported ROLLING THUNDER operations, until 17 October, when an SA-2 alert forced a cancellation. After that period the C-130's and B-57's largely confined their operations to Laos, while the NIGHT OWL F-4C's (with the lead aircraft carrying MK-24 flares in SUU-25 flare dispensers) took over operations in North Vietnam. The increase in night operations

coincided with this switch in aircraft/area responsibility. In the last week of September 1965 and first week of October 1965, six NIGHT OWL sorties were scheduled for every other night (RT 33, 34, and 35).[32] In RT 36 this was raised to eight sorties, and in RT 37, 38, and 39 it was paced at a steady rate of 20 sorties scheduled for every night. In the BR/SL areas the USAF flew 46 B-57 and 12 C-130 NIGHT WIND sorties.

It was in November and December 1965 that night interdiction received its biggest shift, both in direction and weight of effort. It had managed, in its first ten months, to progress from slightly over one night mission (four strike sorties, one support sortie) per week in the BARREL ROLL area, to a fragged 140 sorties per week over North Vietnam and an average of 60 sorties a week in the combined BARREL ROLL/ STEEL TIGER areas. This was a sizeable gain but, even when added to the day effort, it was not appreciably hindering infiltration of either supplies or personnel from North Vietnam to South Vietnam along the overland routes.

Although the RB-66's initiated operations on 8 May 1965 and introduced Elint/ECM to the theater, the level of electronic sophistication was not high. The "wait" restriction between missions should have been evident to the enemy. As a result of such stereotyped tactics,he conceivably knew when it was safe to move and when it was not and varied his movements accordingly. The flares themselves, while necessary in most instances, had their own element of counterproductivity. The ignition of the first flare on a target, visible for many miles, would cause all traffic along a major LOC to pull over under the jungle canopy, turn out the lights and simply

wait. The strike aircraft had but limited loiter capability before bingo fuel was reached. A truck driver had only to sit through a leisurely cigarette or two before he knew he was safe for another few nights. It was estimated that 300 tons of supplies and 4500 Communist soldiers per month were coming into South Vietnam through the LOC's in Laos. It was apparent to military planners in South Vietnam (both United States and Vietnamese) that something had to be done to accelerate the interdiction program. One of the major stumbling blocks to effective counteraction was General Ma's reluctance to accept the high rate of enemy movement reported by U.S. sources, along with his insistence in reserving most of southern Laos for RLAF operations. After observing the lights of enemy vehicular traffic during a night flight, however, General Ma began to alter his views. [33]

To facilitate obtaining authority to resume full scale STEEL TIGER operations, CINCPAC concurred in providing General Ma information regarding anticipated activities in southern Laos. [34] About the middle of November, Ma agreed to the resumption and expansion of USAF air operations in that area. [35]

COMUSMACV accordingly published new operating rules for BR/SL. The most significant policy change was the establishment of armed reconnaissance sectors adjacent to RVN in which strikes could be conducted; with minimum restriction, along any motorable trail or road. [36] He also directed a "think" group to come up with a plan specifically to increase surveillance and promote the actual attack against enemy

troops and supplies along the Laotian border, contiguous to South Vietnam from the DMZ south to Cambodia.[37] In addition, General Westmoreland directed that 2AD schedule up to 100 strike sorties per day into southern Laos and asked the Navy to add another 66, if necessary.[38]

VII. TIGER HOUND

Thus the TIGER HOUND concept was formulated and, for the first time, an integrated program for interdiction was set up. This was briefed to Secretary of Defense McNamara, in Saigon on 28 November, and received his full support.

The night portion of TIGER HOUND envisioned AC-47's as strike and flare aircraft and, also, as Forward Air Controllers when night and weather precluded operations by 0-1 aircraft. The TIGER HOUND task force would have 13 Mohawks (OV-1A's and B's), used to discover targets during darkness with IR and SLAR and, having cockpit readout, could generate fast response to significant findings. General Westmoreland had asked for B-52 strikes in Laos; these would be used at night for several reasons. Among them, it was hoped that Arc Light strikes would escape official detection in order that Prince Souvanna Phouma could maintain a facade of "neutrality" within his own tri-partite government.[39] Also, with these strikes being directed against LOC hubs for the most part, it was felt that the greatest effect would be achieved at night during the hours of peak activity.

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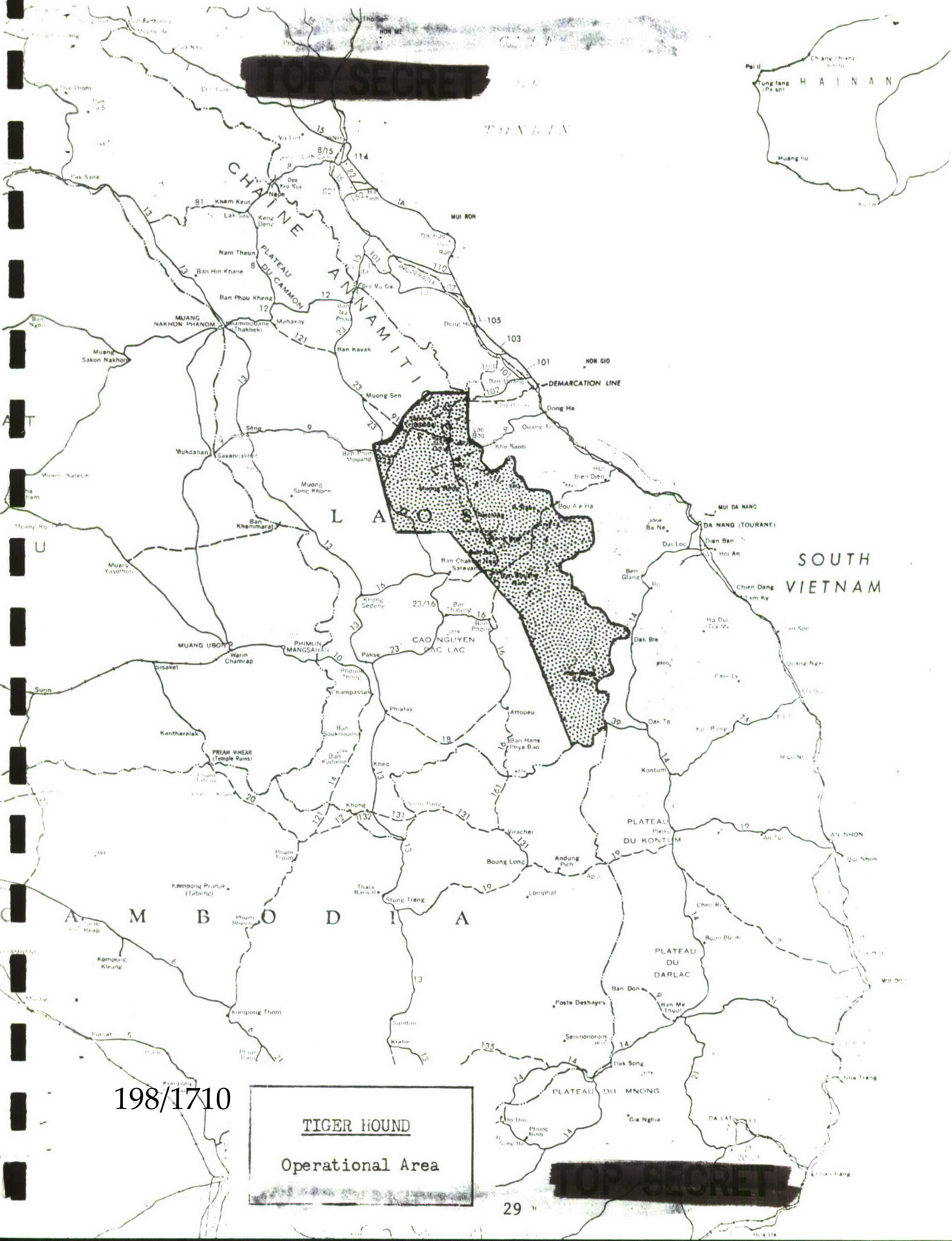

TIGER HOUND

Operational Area

[redacted]

With a valid concept of operation and with a weight of effort finally behind it, it was to take only application and experience to make it pay off. This was a few months in coming. Colonel John F. Groom, Commander of TIGER HOUND Task Force, said:[40]

> "...we admitted that this program at night was more a harassment type thing, rather than trying to find good targets and hit them. Simultaneously, over the well-travelled routes such as Route 9, from Tchepone down south along Route 92, we put in a great deal of night reconnaissance, and the RF-101's going over the area, and the RF-4C, dropping flares at random over seven mile stretches, did pick up actual trucks in the area. This convinced all of us that we had to improve our night effort. So the thing we did was get C-130 aircraft, equipped with flares, on the routes during the nighttime. We would have done this earlier but we were severely limited on flares at this time, and the in-country war came first. But around February, we did receive additional flares, and we started flying the C-130 at six o'clock, until six o'clock.
>
> Recognizing that the photo ships were going over at random and getting trucks, we in a way followed the same tactics. We would have the F-4C's, for example with CBU's, make straight and level runs along roads that we knew were open and were being travelled. And we would drop flares, and have them drop in the area, and we got many many secondary explosions. And the following day, there was evidence that we had gotten quite a few trucks this way.
>
> We still weren't satisfied with this kind of a program. We refined it further by adding the Mohawk - OV-1B aircraft - which is a SLAR equipped aircraft. It has the immediate readout for capability for moving targets. So at the present time, we have a team, consisting of the C-130 with flares, the OV-1B with a moving target capability, and strike aircraft operating as a package. The SLAR aircraft will move up and down the roads and if he gets a moving target indication, he will mark the target with a flare. In turn, the C-130 will pick up this particular coordinate, light up the area and call in the strike aircraft to hit the targets. We try to keep almost a 24 hour pressure - surveillance and attack - on the area, Route 9, 92, Tchepone down south."

The increase in night strike emphasis was justified. From 6 December 1965, when TIGER HOUND started, until 31 December 1965, there were only 51 night strikes compared to 333 day strikes by USAF fighters, or approximately six and a half to one, day to night. In April 1966, the figures were 858 night to 2514 day, a ratio of nearly three to one, and climbing.[41/]

Coincident with the night strike buildup was the night photo recce effort. Through the first ten days of February 1966, fifty night photo missions were scheduled along Route 9 in TIGER HOUND, 21 against Mu Gia Pass, 37 against Nape Pass and 15 against Barthelemy Pass. RB-66's and RF-4C's were tasked with detecting night infiltrations over these passes and along the most likely routes and river crossings. The first series of sorties proved that vehicles were, indeed, moving in quantity.[42/] These night photo aircraft, dropping flash cartridges, took pictures with excellent clarity. (See photo, page 32)

The strikes which followed provided even more drama, since the February results in the TIGER HOUND area exceeded all results previously logged in the program. There were 125 trucks destroyed, another 58 damaged, and 135 secondary explosions. A third of these figures were attributed to night strikes. March results nearly doubled those of February. Here again, the night effort, to a large extent, made it possible. In one instance, an O-1 Forward Air Controller located a camouflaged truck about 40 miles south of Tchepone on Highway 92, late in the afternoon.[43/] He called in strikes which succeeded in blowing

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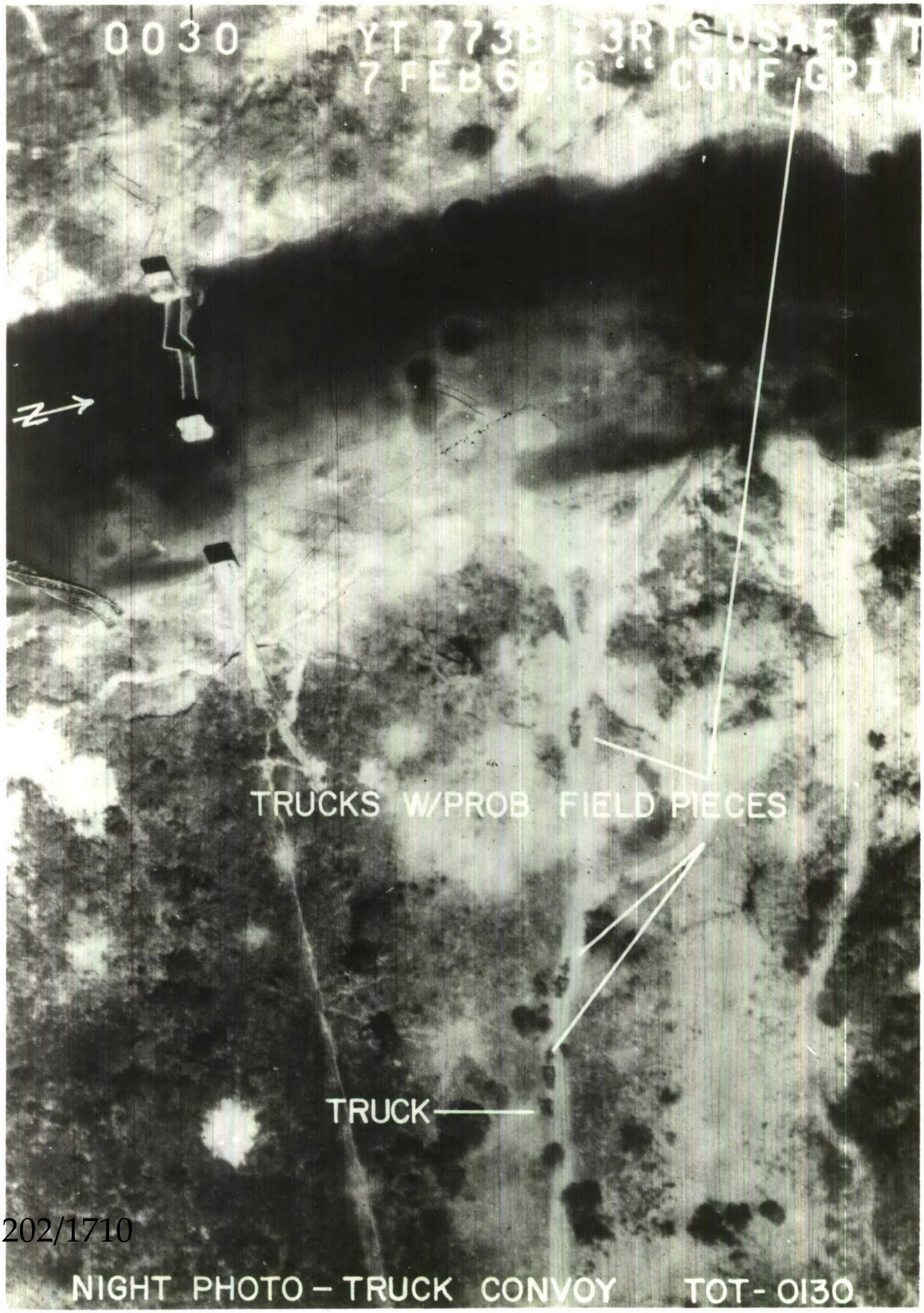
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the camouflage off several more. With more trucks uncovered, the strikes went on into and through the night, under a C-130 flareship, until a total of 215 sorties had been called in. When it was all over, 47 trucks had been destroyed and 28 damaged; secondary explosions were counted until the tally reached 70 and counting became academic. [44]

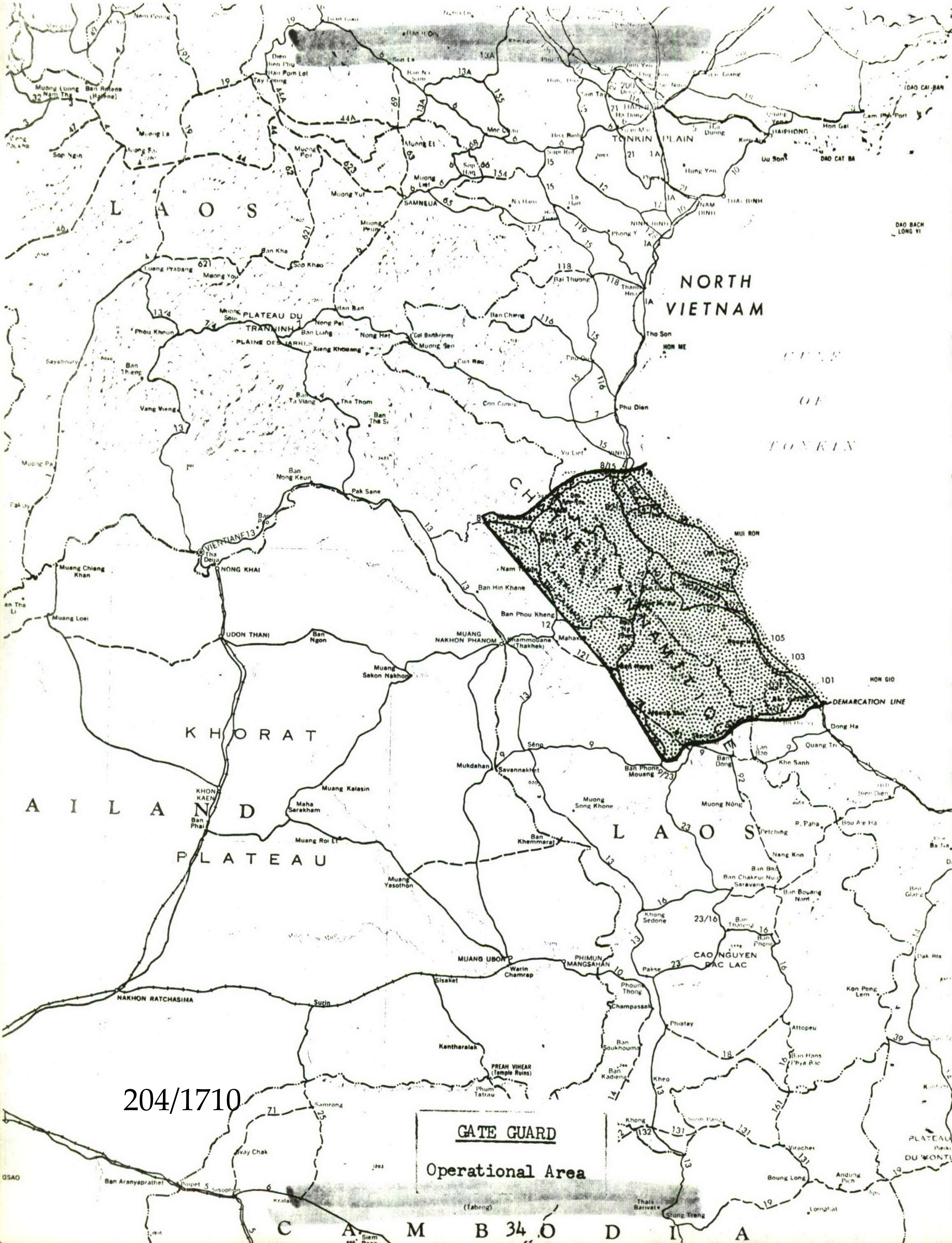
> "...On the first three night strikes, 70 secondary explosions were counted. From there on in, after each strike, a chain of secondary explosions appeared every six seconds. After two hours of bombing, a portion of the area, 50-75 yards in diameter, was like a volcano. Every 6-20 seconds it would erupt with another explosion."

These successes continued to mount through April, which set another all time high (325/205 trucks dest/damaged; 442 secondary explosions) with the night portion receiving its share of the credit. In essence, the program of day/night 24 hour interdiction was so successful that it ran itself out of targets. The decline of truck kills in May foreshadowed the near-absence of truck sightings in June, when the rainy season began.

The concept showed such excellent results that in April and early May the same tactics, with a few notable additions and improvements, were applied in STEEL TIGER North and in Armed Recce Route Package I.

VIII. GATE GUARD

There was a recognized need for more emphasis within North Vietnam of the interdiction program and an operation called GATE GUARD was implemented. More than 1000 trucks were counted during an April



GATE GUARD

Operational Area

survey in RP I and, since TIGER HOUND had nearly sterilized the southern portion of the Laotian Panhandle, it was decided to shift the effort further north. GATE GUARD started in early May in STEEL TIGER North, then concentrated its weight on RP I when the monsoon turned.[45] Like TIGER HOUND, it employed C-130 ABCCC's with flare capability and diversion authority, along with a continuing input of strike aircraft, ECM by RB-66's and gun-laying radar suppression by IRON HAND F-100F's and, later, F-105F aircraft. For night target acquisition, IR/SLAR was used along the coast, with photo-flash recce flown by RF-101's. The object was to interdict selected points along the LOC's during the day then seek out and destroy the fleeting targets at night.

3 april ?

The enemy was determined to keep some semblance of a supply line in operation and went to great lengths to accomplish this. Examples were the removal of steel planking from an airfield runway to shore up interdicted roads, and the sighting (twice) of trucks pulling single railroad cars on undamaged sections of the railroad.[46] To counter this, in July 60 strike sorties per night were scheduled into RP-1, 20 into each of three primary road segments (Rtes 137/1/1A, Rtes 15/15-Bypass and North 101, and Rtes 1A plus South 101). This allowed each section to be covered for 20 minutes of each hour and left flexibility in the event weather denied access to another area - the strikes could simply be diverted into an open sector without saturating the airspace. Six to eight photo sorties were scheduled over selected choke points

each night. The films underwent immediate readout upon landing and, if traffic was noted, word was passed through the TACS (Tactical Air Control System) to the flareships. The flare aircraft proceeded to and illuminated the area, calling in strikes if vehicles were seen. The C-130 flareships would not normally be considered high survivability aircraft for this AAA environment, but RB-66's, as ECM pickets, and Shrike-armed IRON HAND flights negated the effectiveness of the 37/57 mm AAA and restricted ground fire to optically-sighted automatic weapons. Since the C-130's flew, blacked-out, at 6000 feet or above, they were outside automatic weapons range in addition to being very low-visibility targets. If the ECM aircraft were not on station, the C-130's retired to the south and a more permissive environment. Normally, two flare aircraft took position in GATE GUARD, one orbiting a primary choke point midway up the package and the other working random patterns over the other LOC's. The concentration on the night effort showed a marked difference in the number of sorties programmed for the hours of darkness. Roughly one out of 25 or 30 of the sorties for ROLLING THUNDER operations were scheduled for nighttime in October of 1965. In June of 1966 the ratio had risen to one in every two and a half and, in the first few weeks of July, was running in the neighborhood of one night for every two day sorties. In GATE GUARD, the truck kill for night operations surpassed even that for day strikes, which backed up the theme "Interdict in the daytime; exploit at night." In 65 days of operations,

?

See p 35 – between 3 April and 7 July, night strikes had accounted for 164 trucks destroyed and 265 damaged in RP I, while the day effort had gotten 154

destroyed, 126 damaged.[47/]

IX. TALLY HO

The successes in TIGER HOUND had forced the North Vietnamese to recognize this area as unrewarding with regard to their infiltration LOC's. In their frustration, the North Vietnamese began to funnel more troops and supplies directly down through the DMZ, in abrogation of the 1954 accords. To counter this, the assets of TIGER HOUND were given the added responsibility of a new program, Operation TALLY HO. TALLY HO was initiated on 17 July 1966 and the first air strikes were flown on 20 July. The operation area included the southern portion of Rte Package I in North Vietnam from the Dai Giang River, below Dong Hoi, down through the DMZ to its southern boundary. With this new operational area, the last of the overland infiltration LOC's from the north came into the integrated interdiction concept. TALLY HO parallelled TIGER HOUND in concept; in fact, the ABCCC and FAC's from the TIGER HOUND program were used in TALLY HO, along with the Army OV-1B's for night IR/SLAR recce. The ABCCC's did not orbit directly over the DMZ because the area was not permissive. ECM support was generally north of the TALLY HO area. Although area jamming could be provided over the DMZ, whenever higher priority required direct specific jamming, the TIGER HOUND area was without effective ECM. A limiting factor in TALLY HO was the radio/radar limitation caused by mountainous terrain. Adequate radar coverage was limited to 5000 feet and above, if the radar was to track or vector aircraft.

Routes supporting infiltration through the DMZ were 1A, 101, 102, and 103. Route 1A is the principle route to Dong Hoi and,with 102, provided the main route through the DMZ into South Vietnam. Early in the program the Army Mohawks noted moderate traffic moving in small convoys along Rtes 1A, 100, and 101. While it is too early, at this writing, to make a valid comparison between night and day effort in this area, past experience would tend to rate its importance along with that of TIGER HOUND, STEEL TIGER North and GATE GUARD.

X. OPERATIONAL PROBLEMS

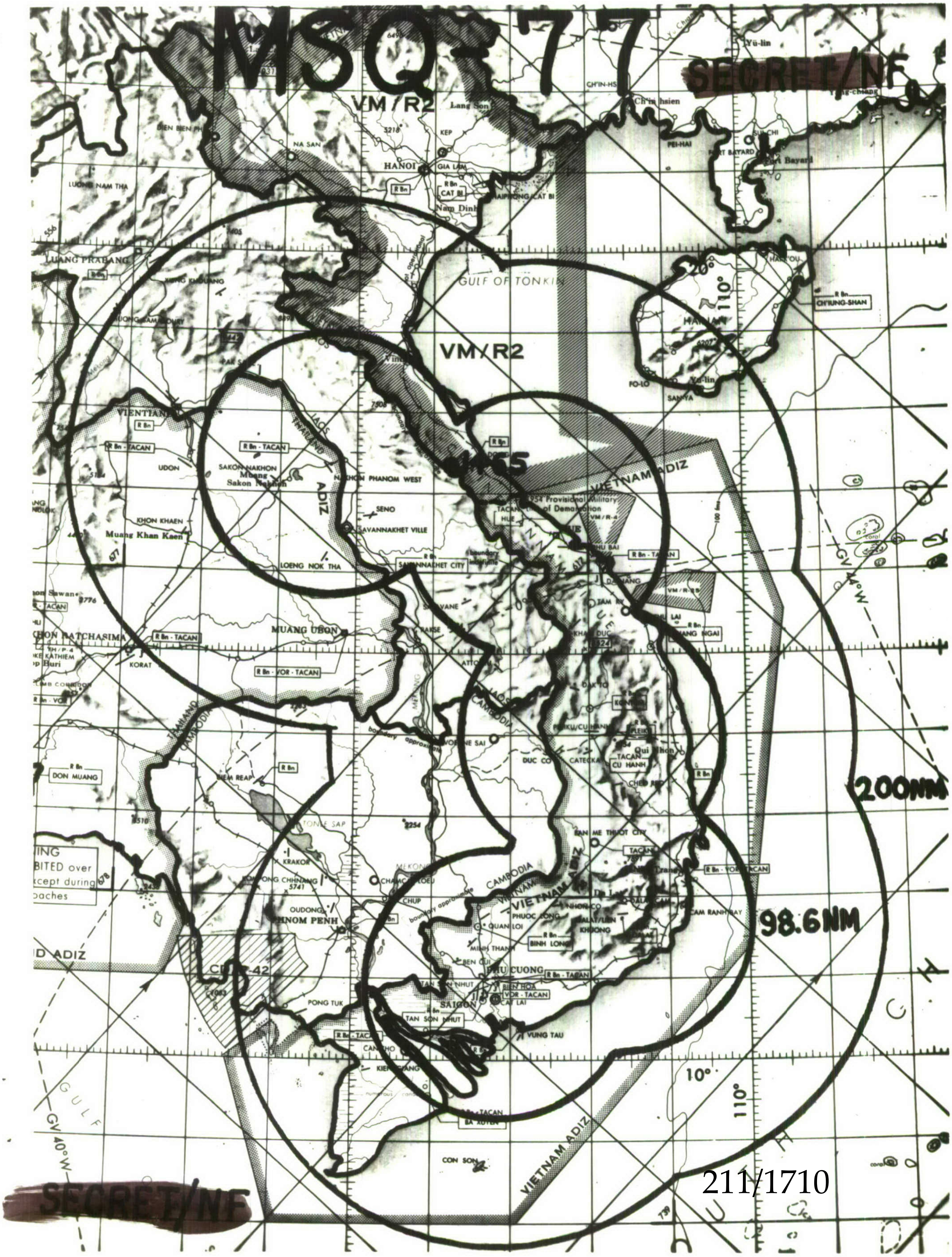
Many problems were encountered and solved during the history of night air interdiction in Southeast Asia. Many were matters of political or self-imposed constraints which were, by-and-large, weeded out and removed in time. Some were inherent to night flying. The possibility of spatial disorientation (vertigo) of the pilots is an ever-present danger. An F-4C was lost in the STEEL TIGER area on 3 April 1966 when the crew was forced to eject after experiencing uncontrollable flight conditions. The aircraft commander was recovering from a steep-angle dive bomb pass under flare illumination. He became disoriented during his pullout when the flare burned out and, subsequently, lost control of the aircraft in a stall or spin condition. Because of darkness, mountainous terrain and low operating altitude, the crew ejected immediately. 48/ Darkness, under conditions of poor visibility, is considered an instrument environment at any time. Tactical fighter operations further degrade this basic safety concept by introducing extreme flight attitudes. The use of flares for target

illumination imposes additional hazards to those expected of night ordnance delivery; the pinpoint bright light and halo make visual range and dive angle computation difficult and uncertain. This has caused steeper than desired dive angles, with greater extremes in recovery and maneuvering attitudes. The smoke of the flares often stratifies and hangs in the target area, creating odd shadow patterns, both in the sky and on the ground, while materially reducing visibility. Flare ignition and burnout create alternating extremes of visibility which affect transition from visual to instrument flying. Night vision adaptation is destroyed at the first flare and is not regained while in the target area.

These conditions are inherent to night combat activities and are accepted as an occupational hazard by the night strike pilot. However, the commanders of the units involved in night operations continued to stress proper division of attention to the attack phase by visual means, and the recovery phase by instrument references. Over-emphasis on either phase would result in lowered ability to destroy targets on one hand, or excessive aircraft risk on the other.[49/] Among other elements tending to reduce flight safety during night operations are muzzle flashes of firing guns or rockets, bomb blasts creating a vast amount of light in one second with complete blackness the next, and nearby thunderstorm lighting flashes creating a "photoflash" effect on the eyes. All these are capable of producing spatial disorientation.

XI. NIGHT WEATHER PROBLEMS (Skyspot)

Night weather, and the attendant problems of navigation and target acquisition, plagued planners from the outset. For example, during ROLLING THUNDER 37 (last week of October 1965) all NIGHT OWL sorties, except for one night's operations, were scrubbed because of poor weather. In ROLLING THUNDER 38 and 39, of 240 sorties scheduled, only 98 were completed, weather being the primary factor, with no aircraft flying on half the nights during the period.[50/] Many attempts were made to alleviate this situation. The use of the Udorn, Korat, Da Nang, and Pleiku TACAN's was ruled out early because of unacceptable CEA's. "Buddy Bombing", a tactic of flying a formation of bomb-carrying fighters with an RB-66 pathfinder and dropping on his lead, was first tried in January 1966. Mu Gia and Nape Passes were bombed several times with this technique. It was well-suited for such bombing where circular error was not critical, but could not successfully be used where an errant bomb might strike friendly forces. MSQ-77, "Skyspot" filled many of the needs for a night/weather bombing system. Skyspot is a ground-based radar and, although orginally developed to score simulated bomb runs over SAC Bomb Plots, its accuracy in vectoring aircraft to a predetermined release point is such that CEA's on the order of 330 feet are the rule.[51/] Any point within range of the MSQ-77 (187 nm if aircraft is beacon-equipped) can be pre-plotted by survey, map measurement or by visually placing an aircraft over that point and plotting its position. The first MSQ-77 was installed 1 April 1966, with four others rushed into completion as soon as possible. The five locations were


MSQ-77
SECRET/NF
VM/R2
HANOI
GULF OF TONKIN
VIENTIANE
VIETNAM ADIZ
200NM
98.6NM
SAIGON
PHNOM PENH
CON SON
SECRET/NF

Bien Hoa, Pleiku, Dalat, and Dong Ha in South Vietnam, and Nakhon Phanom in Thailand. (See Map, Page 41) In final stages of development was a modification to increase the Skyspot range to 200 nautical miles. The advantages of the MSQ-77 system were immediately apparent. Tactical aircraft, not equipped for precision radar bombing, could be used around-the-clock and for all-weather bombing.[52/]

This system, valuable as it was in navigation and in terms of bomb release accuracy, could not solve the target acquisition problem for night armed reconnaissance. Weekly, SEAOR (Southeast Asia Operational Requirement) requests were sent back to AFSC in hopes of beating this continuing problem. The RB-57, RF-4C, and OV-1B aircraft, with their IR/SLAR capabilities, had limitations both in resolution and in heat-selectivity. The equipment in the RB-57 was incapable of resolving a truck-sized vehicle, for instance. The Mohawk, with somewhat better resolution and with cockpit readout capability, had advantages but was forced to operate at altitudes of 1500 feet or below, which placed it within automatic weapons range. Five were lost during the TIGER HOUND program to small arms and AW, two on one day.[53/]

The Starlight Scope, a light-intensifying telescope, was used with outstanding success in locating enemy personnel on the ground at Attopeu, Laos on 4 March 1966, but these were in short supply.[54/] An SEAOR was submitted for this equipment, both individual and crew-served, for use in the AC-47 and the O-1 aircraft. The AFSC Best Preliminary Estimate (BPE) was sent to USAF, but no schedule could be given. Obtaining

quantities of Starlight Scopes would probably require DOD approval since all production was currently slated for immediate delivery to Army combat units in South Vietnam.[55] Because flares normally alert the enemy to the possibility of an imminent airstrike, several SEAOR's were submitted and projects began to come up with an aircraft/sensor combination which could achieve the element of surprise. The Starlight Scope was only one, others were: Project Lonesome Tiger (the installation of Forward Looking IR (FLIR) in B-26K's for use in night armed recce), Project 1533 (Four A-1E's carrying Dalmo-Victor Low Light-Level TV pods for night armed recce) and Project Black Spot (C-123 aircraft with weapons and night sensor equipment, FLIR, LLLTV, and/or radar, as night armed recce test beds).[56] Flight tests were scheduled to begin for Project Lonesome Tiger in October; Project 1533 was to start testing in July of 1966 and deploy to SEA in October. It was planned to test the Black Spot C-123's in December, with deployment to SEA set for January 1967.[57]

Among other systems or combinations which were asked for were Foliage Penetration Radar, Laser Photo Reconnaissance equipment, and Data Link or cockpit readout of higher resolution/sensitivity IR/SLAR.[58] The last was considered highly important. An SEAOR was submitted to procure a system which would permit night reconnaissance infra-red sensor image data to be imaged in near real time (hopefully, one minute) at a remote air or ground readout facility. Image interpreters at the facility would quickly interpret the IR image and immediately transmit derived

targeting information to a strike capability before the target appreciably changed, moved or dispersed. The time delay currently experienced with USAF aircraft, which had to return to base, download and have the data processed before interpreters could derive targeting or other intelligence from it, unquestionably allowed many lucrative targets to escape. Such information is normally highly perishable. If tactical aircraft could be modified to provide such real time imagery, the time elements of the acquisition/target/strike cycle would be reduced to those required for human analysis and direction.[59/]

XII. AC-47's

Along with the "very new" in night operations came the "very old." The AC-47 "Puff" aircraft had been tested and adopted in South Vietnam in December 1964 and January 1965. On 10 January 1966, the USAIRA at Vientiane asked 2AD to establish a requirement for six to eight AC-47's at Nakhon Phanom, for use in Laos.[60/] Second Air Division did so on 5 February. On 17 February, urgent phone calls from Deputy Commander 2AD/13AF Thai requested AC-47's immediately for the defense of Lima Site 36, an Air America strip in northern Laos. Two aircraft were immediately sent to Udorn for use in that engagement. Although Lima Site 36 was lost, the AC's made such a good showing that the Ambassador to Laos and the AIRA requested they be left at Udorn permanently. On 19 February, CINCPAC directed that an acceptable number of AC-47's be sent to Nakhon Phanom in the immediate future. PACAF, in turn, directed 2AD to have MACV allow the deployment of four AC-47's

to NKP for use in CRICKET (STEEL TIGER North).[61] These four, with five crews, were scheduled to Udorn for 179 days TDY. Thai country-clearance was obtained on 25 February and, on 26 February, the four AC's deployed.

The venerable Gooney would not appear to show a high survivability factor in the SEA environment and six AC-47's were lost during the first eight months of operations. However, most losses, if not all, were incurred in an out-of-design role. Blacked-out at night, flying above AW range, its chances for survival should be excellent; flying low, or in an AAA envelope, they would be slim. Most of the losses appeared to be directly attributable to AW or AAA.

The four aircraft sent to Udorn remained there until A-1E's ("Sandy" low-rescap aircraft) arrived and created over-crowded ramp conditions. The AC's then moved down to Ubon, Thailand. With the arrival of eight A-26A's at Nakhon Phanom on 18 June, the AC-47's moved back to South Vietnam, having fulfilled their mission in Thailand and Laos.

XIII. EPILOGUE

Southeast Asia night operations, in the interdiction role, have progressed tremendously in the year and a half since their beginnings. From a toddling start, in January 1965, when four airplanes wandered about looking for a place to unload ordnance, through June of 1966, when 1903 night armed recce sorties helped seal off the overland

infiltration routes into South Vietnam, the program has made great strides. In weight of effort it has grown massive; in tactics, it has achieved a real measure of efficiency; in total effectiveness, it has proved a necessary adjunct to an integrated interdiction program.

NIGHT INTERDICTION IN SOUTHEAST ASIA

Footnotes

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1 NOVEMBER 1972

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PYROTECHNIC FLARE SPECTROSCOPY III

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RESEARCH AND DEVELOPMENT DEPARTMENT
NAVAL AMMUNITION DEPOT, CRANE, INDIANA

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NAVAL AMMUNITION DEPOT
RESEARCH AND DEVELOPMENT DEPARTMENT
CRANE, INDIANA 47522

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1 November 1972

PYROTECHNIC FLARE SPECTROSCOPY III

BERNARD E. DOUDA

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FORWARD

This paper was prepared for presentation at the annual NAVAIR review of its sponsored research programs in the field of Energy Conversion (non-propulsive aspects) to be held on 8-10 November, 1972, at the Naval Weapons Center, China Lake, California. The work is sponsored by the Research and Technology Group of the Naval Air Systems Command. Dr. Hyman Rosenwasser is the program Manager in NAVAIR.

The progress report for fiscal year 1971 is contained in RDTN No. 201, Pyrotechnic Flare Spectroscopy, Naval Ammunition Depot, Crane, Indiana, 1 November 1971.

PYROTECHNIC FLARE SPECTROSCOPY

Bernard E. Douda

Naval Ammunition Depot, Research and Development Department, Crane, Indiana 47522

Scientific Background

Illuminating flares are typically made from a mixture of magnesium, sodium nitrate, and a binder. Light is emitted from these flares at a luminous efficiency of about 50,000 candle-seconds/gram. To satisfy the continuing need to generate light more efficiently, the specific objective of this work is directed toward determining the mechanisms by which light is emitted from illuminating flames, the new knowledge providing the basis for future improvements.

The approach being taken is to study emission spectra of illuminating flames tested at various pressures and with different formulas. The aim of these studies is to relate the experimental observations to some set of parameters which characterizes the state of the flame. Theoretical models and prediction equations are being developed which predict the flare output based on knowledge of the flare formula, flare size, and ambient pressure.

Status

The initial experiments to obtain spectra for validation of the theoretical model and the prediction equations have been completed. The computation of the sodium atom density in the experimental flames and computation of the effective adiabatic flame temperature are finished. The preliminary computation of the theoretical spectra using a local thermal equilibrium, LTE, radiative transfer model shows good agreement with the experimental spectra. Details of the basis for this work and interim reports of recent phases are included in references 1 through 4.

Significance of the Study

This research is intended to provide a better understanding of how light is generated by a pyrotechnic illuminating flare. Several significant advances have come about from this work:

1. Atomic sodium in the illuminating flame was shown[1] to be the dominant emitter in the visible region.

2. The major portion of the total flux radiated by flames from magnesium-sodium nitrate flares is due to emission from broadened sodium D lines, the broadening being a function of pressure, sodium atom density, and related parameters.

3. The LTE radiative transfer model, as we have constructed it, can be used to predict illuminating flame output with knowledge only of the flare formula, flare size, and ambient pressure at which

the flare is burned. The model can readily be generalized to predict the spectral output of flares containing any of the alkali metals making the model useful for a variety of pyrotechnic problems in addition to illumination.

Progress (July 1971 - October 1972)

Three groups of flares were made with the following formulas:

	Group 22	Group 25	Group 26
Magnesium	44.0%	40.40%	40.04%
Sodium Nitrate	51.5%	5.15%	0.515%
Potassium Nitrate		49.95%	54.945%
Binder	4.5%	4.5%	4.5%

The distinguishing feature is the change in sodium nitrate concentration by substitution of potassium nitrate. Spectra were obtained of the emission from these flares while burning at pressures between 760 and 6 torr. A summary of the spectral data is provided in Figure 1. The figure clearly shows the change in spectral distribution of the flux radiated by the flame as the ambient pressure and/or sodium atom density change. It is this feature which is of primary interest.

By visual inspection of Figure 1, we can observe the influences that sodium atom density and ambient pressure have on the distribution of emitted power. First, for Group 26 at 30 torr, we see two lines in emission separated 6 Å, each showing an absorption region at their respective line centers. The rather narrow lines are due to emission

from the sodium D_2 and D_1 lines. As the pressure is increased from 30 torr to 75 to 150 to 225 torr, we observe the broadening of each of the lines with the absorption region at line center getting wider and deeper. As the pressure increases and the broadened lines overlap in an increasing amount, we see a coalescence of the two lines halfway between them, becoming completely filled near 300 and 630 torr. As the pressure increases to 760 torr, the lines and absorption region broaden even further causing the region between the lines to become less intense in relation to the maxima on either side of the D line center frequency.

To obtain input values for effective flame temperature and sodium atom density for use in the radiative transfer model we used the computational procedures described by Gordon and McBride[5]. The results, estimating a 30 percent enthaply loss, are given in Figure 2. The values are used to solve the LTE case of the differential equation[6] for radiative transfer,

$$dI_\nu/d\tau = \phi_\nu(a)\ [I_\nu - B_\nu(T)] \qquad (1)$$

where ν is frequency, B is the Planck function, T is temperature, τ is optical thickness, ϕ is the 2-line Voigt profile, the Voigt profile a is the ratio of the sum of the resonance and collisional half widths to the Doppler half width, and I is the emergent intensity in a direction normal to the flame. Integration of equation (1) to find the emergent

intensity on the surface of the flame (τ = 0) with no energy incident on the rear of the flame yields,

$$I_\nu = \phi_\nu(a) \int_{t=0}^{t=z} B_\nu(T) \exp(-\tau(t)\ \phi_\nu(a))\ dt \qquad (2)$$

where Z is the thickness of the flame (cm).

A parabolic temperature gradient is constructed in the model using the computed temperature given in Figure 2 as the temperature at flame center. The boundary temperature is taken to be 1200°K. The appropriate Planck value is computed as a function of frequency and temperature through the flame medium. A two-line Voigt profile, weighted for line oscillator strength, is constructed numerically to approximate the line distribution due to resonance and collisional broadening. The appropriate value of the Voigt a parameter is taken from Mitchell and Zemansky[7]. The computed sodium atom densities, given in Figure 2, are used in the model to compute the flame optical thickness. The physical flare size is estimated from photographic records.

When the radiative transfer equation containing all the necessary inputs is solved, we obtain a spectral radiant power distribution which can be compared to the experimental spectra. Examples of some of these spectra are compared in Figure 3 for Group 26 formulations. Visual inspection of these spectra shows that the theoretical spectra on the right have nearly the same spectral distribution as the experimental spectra on the left.

Experimental and theoretical values of delta lambda, the distance in Angstroms from the sodium D_2 line center to its blue maximum, are also compared in Figure 3. The agreement between these values is also considered acceptable. Other tests for agreement between the theoretical and experimental spectra will be reported as the work progresses.

Concluding Remarks

The model is being tested over a wide range of pressure and sodium atom density. It appears that the agreement between theory and experiment will turn out to be good enough for one to conclude that the model is valid, making it useful in its present form for predicting the output of a large variety of pyrotechnic flares.

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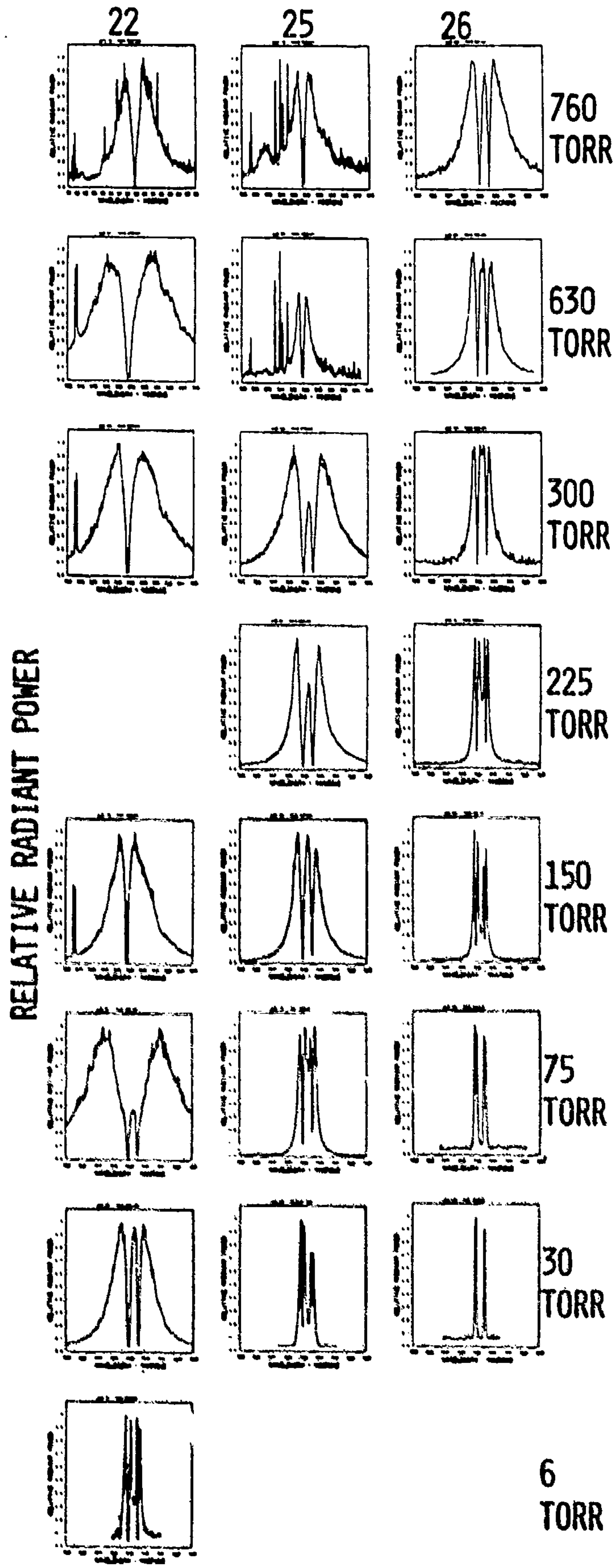
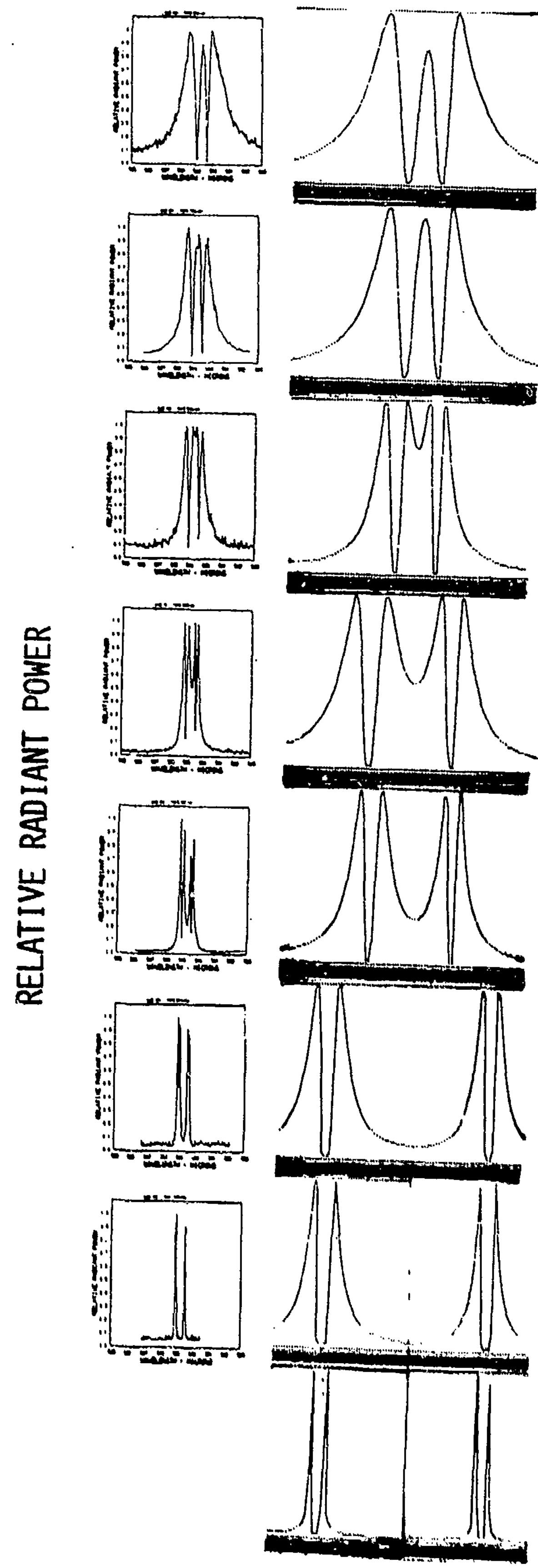


Figure 1. Relative radiant power spectra in the visible region of three illuminating flame formulas (Groups 22, 25, and 26) at ambient pressures between 760 and 6 torr.

MAGNESIUM NANO3 KNO3 BINDER PRESSURE	44.0 51.5 - 4.5 GROUP 22	40.4 5.15 49.95 4.5 GROUP 25	40.04 0.515 54.945 4.5 GROUP 26
760	2939 1.01×10^{18}	2905 1.10×10^{17}	2904 1.11×10^{16}
630	2920 8.46×10^{17}	2887 9.20×10^{16}	2886 9.26×10^{15}
300	2842 4.08×10^{17}	2816 4.44×10^{16}	2815 4.47×10^{15}
225	2812 3.08×10^{17}	2788 3.34×10^{16}	2787 3.37×10^{15}
150	2770 2.07×10^{17}	2748 2.24×10^{16}	2747 2.26×10^{15}
75	2698 1.05×10^{17}	2680 1.14×10^{16}	2679 1.15×10^{15}
30	2606 4.29×10^{16}	2592 4.65×10^{15}	2591 4.67×10^{14}
6	2453 8.90×10^{15}	2443 9.63×10^{14}	2442 9.70×10^{13}

Figure 2. Computed adiabatic reaction temperature (upper number in °K) and sodium atom density (lower number, atoms/cm^3) for three illuminating flame formulas (Groups 22, 25, and 26) at ambient pressures between 760 and 6 torr. Thirty percent enthalpy loss is assumed.



	DELTA CALC	LAMBDA EXP
760 TORR	3.87	3.81
630 TORR	3.38	2.73
300 TORR	1.71	2.13
225 TORR	1.13	1.14
150 TORR	0.74	0.85
75 TORR	0.44	0.54
30 TORR	0.20	0.22
6 TORR	0.12	

Figure 3. Comparison of experimental radiant power spectra (left column) at pressures between 760 and 30 torr to theoretical spectra (right column) computed by using an LTE radiative transfer model. Experimental and theoretical values of delta lambda, the distance in Angstroms from the sodium D_2 line center to its blue maximum, are also computed.

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DEVELOPMENT AND OPTIMIZATION OF FLOW-CAST MAGNESIUM FLARE COMPOSITIONS

THE DOW CHEMICAL COMPANY

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Development And Optimization Of Flow-Cast Magnesium Flare Compositions

George A. Lane
Erwin M. Jankowiak
Keith Roberson

FOREWORD

This report covers work performed during the period 21 April 1971 to 14 February 1972 by the Dow Chemical Company, Midland, Michigan, under Contract F08635-71-C-0120, "Development Program for Optimizing Flow-Cast Flares", with the Air Force Armament Laboratory, Eglin Air Force Base, Florida. Captain Robert Dowrie (DLIP) was program monitor for the Armament Laboratory.

Management direction at The Dow Chemical Company was under Dr. E. T. Niles, and technical supervision under Dr. G. A. Lane. Major contributions were made by Erwin M. Jankowiak and Keith Roberson.

This technical report has been reviewed and is approved.

Franklin C. Davies

FRANKLIN C. DAVIES, Colonel, USAF
Chief, Flame, Incendiary, and Explosives Division

ABSTRACT

Previous work (Contract F08635-70-C-0028, Eglin Air Force Base) gave encouraging results for flow-cast illumination flares. The present development effort has resulted in compositions comparable in performance with pressed mixtures. Viton®-lined paper phenolic cases have proved satisfactory in 3.4-inch-diameter size. The agglomeration of sodium nitrate can be reduced by the addition of MgO and Cab-O-sil. However, the oxidizer also should be used immediately after grinding to avoid agglomeration. Surfactants can be used to improve mix viscosity. The particle size distribution of magnesium used is critical to mix viscosity and luminous efficiency. With 20 percent binder in the mix, maximum performance is obtained at about 52 percent Mg for 1.25-inch candles and 50 percent Mg for 3.4-inch candles. The best efforts formulation contains 50 percent of a 40/200 mesh Mg blend, 30 percent $NaNO_3$, and 20 percent of XFS-4008L - EC-MA - DEGDN binder. In 3.4-inch candles it yields 43 to 45,000 cd-sec/g efficiency at 0.056-0.059 in./sec. burning rate. This mix has been scaled up to 10-kg batch size. Further work has also been accomplished on new binders. The most promising is based on a vinyl ester, Tex-R-1939, plasticized with DEGDN.

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GLOSSARY

ADGC - allyl diglycol carbonate.
AGE - allyl glycidyl ether.
AOPG - allyloxypropyl glycidyl ether.
DEGDN - diethylene glycol dinitrate.
D.E.H.® 20[1] - diethylenetriamine.
DETA - diethylene triamine.
EC - ethylene carbonate.
EC-MA - 1:1 solution of ethylene carbonate and maleic anhydride.
EDA - ethylene diamine.
HEA - hydroxyethyl acrylate.
MA - maleic anhydride.
MEK - methyl ethyl ketone.
PGNC - plastisol grade nitrocellulose.
TEA - triethanolamine.
TEGDN - triethylene glycol dinitrate.
XF-4013L - sulfur - containing epoxy resin.
XFS-4008L - glycerine diglycidyl ether.

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[1]D.E.H., a trademark of The Dow Chemical Company for epoxy curing agent.

SOURCES OF MATERIALS

ADGC - PPG Industries
AGE - Alcolac, Incorporated
AOPG - The Dow Chemical Company
Cab-o-sil M-S - Johns Manville Company
Cumene Hydroperoxide - Hercules, Incorporated
Crystal Bay Tape - 3M Company
DEGDN - Commercial Solvents Corporation
D.E.H.® 20 - The Dow Chemical Company
DETA - The Dow Chemical Company
Diethyloxalate - Eastman Kodak Company
Dowanol EM - The Dow Chemical Company
EC - Jefferson Chemical Company
EDA - Eastman Kodak Company
Ethylene Glycol - The Dow Chemical Company
HEA - The Dow Chemical Company
Lauroyl Peroxide - Chemtron Noury Corporation
MA - Matheson, Coleman and Bell Company
Magnesium, Atomized - Valley Metallurgical Products Company
Magnesium Oxide - Allied Chemical Company
MEK Peroxide - Pennwalt Corporation
Mylar® Film - E. I. Dupont de Nemours and Company
PGNC - E. I. Dupont de Nemours and Company
Potassium Chlorate - American Potash and Chemical Company
Sodium Nitrate - Davies Nitrate Company
Sprayon Paint - Sprayon Products, Inc.
Tartaric Acid - J. T. Baker Chemical Company
TEA - The Dow Chemical Company
TEGDN - Propellex
Tergitol E-35 - Union Carbide Corporation
Tex-R-1939 - The Dow Chemical Company
Viton® - E. I. Dupont de Nemours and Company
XF-4013L - The Dow Chemical Company
XFS-4008L - The Dow Chemical Company

SECTION I

INTRODUCTION

The objectives of this effort were to optimize the best efforts castable magnesium-sodium nitrate flare composition developed under Contract No. F08635-70-C-0028, "Flow Cast Flare Composition," and to develop new compositions based on new binders.

The best efforts formula from the previous contract contained 22% binder, consisting of 25% XFS-4008L, 35% EC-MA (ethylene carbonate-maleic anhydride in a 1-1 ratio), and 40% DEGDN (diethylene glycol dinitrate). The total composition contained:

52%	Magnesium, 40/200 mesh
26%	$NaNO_3$, <400 mesh
5.5%	XFS-4008L
7.7%	EC-MA
8.8%	DEGDN

The basic characteristics were:

Viscosity at 25°C - 563,000 cps
Luminous Efficiency - 70,000 cd-sec/g
Burning Rate - 0.056 in./sec.
Grain Integrity and Surveillance
Stability - Acceptable

In order to compare light output and efficiency with known flare compositions, pressed candles containing the composition used in Mark 45 flares were fired at frequent intervals in conjunction with firings of the developmental flares. The best efforts flow cast composition was expected to give about 5,000 cd-sec/g less luminous efficiency than the pressed Mark 45 composition at approximately the same burning rate.

The present effort was directed at investigating the various parameters that might contribute to a reduction in binder level and improvement in light output without sacrificing the physical and stability properties of the best efforts flare composition. This work also included restandardization of light measuring equipment, investigation of inverted flare firings, adapting for the use of 3.4 inches ID paper-phenolic cases, studying $NaNO_3$ particle size and dispersion, and investigating magnesium particle size distribution.

A second objective was to continue development of new and improved binder systems for flow-cast magnesium-$NaNO_3$ illuminating flares.

SECTION II

PROCEDURES

The following experimental conditions were used, unless specified otherwise in the report:

1. Sodium nitrate - Powdered Davies $NaNO_3$, containing 0.50 percent MgO and 0.25 percent Cab-o-sil, was ground in a Mikro-Pulverizer and dried at least 16 hours at 80°C.

2. Magnesium - atomized 40/200 mesh Valley Metallurgical Mg powder was used. The work reported was done with different batches of 40/200 mesh material (see page 14 for mesh analyses).

3. TEGDN or DEGDN - No inhibitor.

4. Mixing - All work was done with a KitchenAid model K5-A mixer, wire whip blade at minimum speed. The following procedure was adopted: Add epoxy resin, curing agent and plasticizer; mix 1 to 2 minutes; add $NaNO_3$; mix 5 to 10 minutes; add Mg; mix for 10 to 15 minutes. Batches of 420 to 8000 g were prepared.

5. Fluidity - The viscosity was determined on an aliquot sample of the mix at 25°C using Brookfield RVF viscometer with T-type spindle.

6. Casting - The composition was poured into a 6-inch plastic funnel, and allowed to flow into a mold or flare case. Four to six candles (100 or 1200 g) were prepared per batch.

7. Mold - For the tape-wrapped candles a 1-1/4 inch I.D. by 4-inch long cardboard tube was lined with Mylar® film and plugged at the bottom with a No. 7 neoprene stopper. The mold was filled to a depth of 3.4 to 3.5 inches. When a case was used, the mix was poured directly into the prepared flare case.

8. Curing - Candles were cured at 70°C for 16 to 40 hours, depending on circumstances.

9. Tape Wrapping - The cured candle was removed from the mold, weighed and measured, reinserted into the mold, and an epoxy-sand plug was cast and cured at 20°C on the top (uppermost during casting) surface. Candles were removed from the mold, sprayed with Sprayon No. 321 paint for case-bonding and spirally wrapped (bifilarly) with Crystal Bay (2-inch width) masking tape. About 1 inch extra case was left at the top for the igniter. A very small overlap of tape was used, resulting essentially in a 2-ply case.

10. Density - Density was determined geometrically from the weight and measured size of the candle.

11. Igniter - The following composition was mixed, cast, and cured as a 0.5-g igniter pellet, attached to a length of igniter cord.

11.8%	Mg, 100/200 mesh
54.0%	$KClO_3$, Class 7
19.8%	XF-4013L
12.6%	MA
1.8%	Nitrocellulose powder

12. Attitude - The 1 1/4-inch candles were burned vertically, ignited on the upper surface. Air flow was upward. The 3.4-inch candles were tested both in this position and inverted.

13. Flare Tunnel - The flares were fired in an 18-foot 8-inch deep by 10-foot 5-inch wide by 10-foot 4-inch high concrete block hearth. The bottom of the flare was 4 feet 9 inches above the floor. Ventilation was accomplsihed by an inlet in the floor below the flare and an external 2-speed blower above the flare in the roof. The flare tunnel itself, connected to the hearth by a 4-foot by 9-foot doorway, is 60 feet long by 10 feet 5 inches wide by 14 feet high. The interior of the hearth and tunnel are painted black.

14. Light Measurement - Two Model 856 YYV Weston selenium photovoltaic cells are positioned 51.95 feet and 62.57 feet from the flare, at heights above the floor of 5.1 and 5.5 feet. The outputs of the photocells are amplified by Honeywell Accudata 120 amplifiers. Light output is recorded on a Honeywell Model 906B Visicorder oscillograph. A Dymec Model 2210 voltage-to-frequency converter and a Hewlett Packard Model 523 CR electronic counter are used to integrate the light output and record the integrated luminosity.

The photocell is standardized with a General Electric Lamp No. 1M/T20BP, which at a constant amperage yields a specific horizontal candle-power.

15. Burning Time - Time of functioning was determined visually with a stop watch.

16. Replications - At least four candles were fired for each data point.

SECTION III

CASE STUDY

A. PAPER-PHENOLIC CASES (1.25-INCH DIAMETER)

It was desired that optimization be conducted on compositions encased in 3.4-inch paper-phenolic tubing. Initial studies were conducted in 1.25-inch diameter paper-phenolic cases to determine the compatibility and case bonding properties of this composition with the case material. As shown in Table I, initial tests showed a failure in case bonding, as indicated by marked increase in combustion rate and reduction in luminous efficiency. Lining paper-phenolic cases with Viton® lacquer (3,000 to 3,500 cps, acetone-Viton® solution) gave enough improvement to warrant an immediate investigation of Viton®-lined paper-phenolic cases of 3.4-inch diameter.

TABLE I. COMBUSTION BEHAVIOR OF CANDLES IN PAPER-PHENOLIC TUBES

	Cast Composition[a]			Mark 45 Composition
	1.25-inch Paper-Phenolic			
	Unlined	Viton®-Lined	Paper-Tape	Paper Tape
Burn Rate in/sec	0.086	0.046	0.055	0.063
Efficiency cd-sec/g	24,000	39,200	49,800	57,300
Flame	Split	Smooth Straight	Smooth Flared	Smooth Straight
Chimney	Large	Small	None	V. Slight

[a]50.29 percent magnesium, 27.71 percent $NaNO_3$, 5.96 percent XFS-4008L, 8.04 percent EC-MA, 7.70 percent DEGDN.

B. PAPER-PHENOLIC CASES (3.4-INCH DIAMETER)

Initial investigation yielded consistently low luminous efficiencies for 3.4-inch candles in Viton®-lined paper-phenolic cases, when fired in either the upright or inverted position. This was attributed primarily to chimney effects. However, smoke obscuration also was evident in the inverted

firings. The data in Table II indicate good case bonding with the 0.110-inch wall cases. Attempts were made to overcome the chimney effect and improve luminous efficiency by (1) reducing wall thickness from 0.110 inch to 0.055 inch and (2) using cases with 1/2-inch alternating bands of 0.110-inch and 0.056-inch thickness or 0.077-inch and 0.056-inch thickness. As may be seen in Table II, good case bonding and higher luminous efficiencies were achieved in some tests. However, because the 0.055-inch wall proved unacceptable, and the 0.077-inch wall was unpredictable, further work was done on flare preparation procedures. This showed that modifications in casting and case-bonding procedures resulted in acceptable combustion behavior for the 0.110-inch wall 3.4-inch I.D. paper-phenolic cases. These data are shown in Table III.

Good combustion results were obtained by using a thinner Viton lining (2,500 to 2,700 lacquer viscosity), and by bonding the epoxy-sand plug to the flare base. Efficiencies comparable to the ribbed case and approaching the results with 2-ply paper tape were obtained. This type of case and method of flare preparation were adopted for optimization purposes.

C. FISH PAPER AND COTTON-PHENOLIC CASES

Data are presented in Table IV for 1.75-inch diameter fish-paper cases. The thicker 1/16-inch wall cases give the best results in the inverted position. Flare composition XFS-4008L - EC-MA - DEGDN) cast in these Viton®-lined cases displays a luminous efficiency and burning rate equivalent to the 2-ply paper-tape wrapped case. Interestingly, lining of the fish-paper cases with Viton® is detrimental in the thinner 1/32-inch wall cases. This strongly suggests that Viton® contributes to case bond failure during functioning in this case. The 1/16-inch wall thickness appears practical for either lined or unlined cases.

Cotton-phenolic cases were tested (0.075-inch wall) and displayed good case-bonding, as indicated by the burning rate 0.055 in/sec. However, luminous efficiency, 20,000 cd-sec/g, was surprisingly low, considering there was no residual chimney.

Thus, the preferred 1.75-inch diameter case appears to be 1/16-inch wall fish-paper, followed closely by the Viton®-lined paper-phenolic. Fish-paper cases need to be investigated for 3.4-inch diameter candles.

TABLE II. STUDY OF 3.4-INCH DIAMETER FLARES[a]

Number of Firings	Case	Case Wall (inch)	Flare Attitude	Burn Rate (in/sec)	Luminous Efficiency (cd-sec/g)
2	Viton®-lined paper phenolic	0.110	Upright	0.057	30,600
2[b]	Viton®-lined paper phenolic	0.110	Inverted	0.056	27,800
1	Viton®-lined paper phenolic	0.077	Inverted	0.063	46,700
1	Viton®-lined paper phenolic	0.077	Inverted	0.132	27,800
1	Viton®-lined paper phenolic	0.077	Inverted	0.105	21,800
1	Viton®-lined paper phenolic	0.077	Inverted	0.106	23,200
2	Viton®-lined paper phenolic	0.055	Upright	0.122	27,400
2	Viton®-lined paper phenolic	0.055	Inverted	0.138	24,800
1	Viton®-lined paper phenolic	0.077-0.056[c]	Inverted	0.074	45,200
1	Viton®-lined paper phenolic	0.110-0.056[c]	Inverted	0.057	43,400
2	2-ply paper tape	---	Upright	0.052	51,400

[a]Composition 52/26/22 - Mg/$NaNO_3$/XFS-4008L - EC-MA - DEGDN.

[b]Flare and case fell during functioning of one flare. Data based on single flare.

[c]Banded case, alternating 1/2-inch segments of different thickness.

TABLE III. EFFECT OF PREPARATION METHOD OF 3.4-INCH DIAMETER FLARES

Composition (%)[b]			Case	Case Wall (inch)	Viton® Lining	Burn Rate (in/sec)	Luminous Efficiency[a] (cd-sec/g)
Mg	$NaNO_3$	Binder					
52	26	22	Unbonded sand plug[c,d]	0.110	Heavy[e]	0.056	27,800
52	26	22	Bonded sand plug[c]	0.110-0.056 Banded	Thin[f]	0.055	43,400
52	28	20	Bonded sand plug[c]	0.110	Thin	0.061	42,600
50	30	20	Bonded sand plug[c]	0.110	Thin	0.059	45,000
52	26	22	2-Ply paper tape	--	--	0.052[g]	51,400[g]

[a]Inverted firings.

[b]XFS-4008L - EC-MA - DEGDN.

[c]Paper phenolic case.

[d]Dow Corning release agent between sand plug and flare base.

[e]Initial Viton® linings not measured but estimated at significantly thickner than 0.0035 inch.

[f]Measured to be 0.0035-inch thick.

[g]Upright firing.

TABLE IV. STUDY OF 1.75-INCH FLARES IN FISH-PAPER CASES[a]

Number of Firings	Case	Wall Thickness (inch)	Flare Position	Length (inch)	Density (g/cc)	Weight (g)	Burn Rate (in/sec)	Luminous Efficiency (cd-sec/g)
4	Viton®-lined fish-paper	1/16	Inverted	3.59	1.63	229.8	0.053	44,000
4	Viton®-lined fish-paper	1/32	Inverted	3.52	1.64	237.4	0.121	25,000
2	Unlined fish-paper	1/16	Inverted	3.78	1.55	231.5	0.064	41,000
1	Unlined fish-paper	1/32	Inverted	2.60	1.57	164.5	0.060	40,700
4	2-Ply[b] paper-tape	--	Upright	4.07	1.62	125.9	0.057	41,700

[a]Composition - 52/26/22 - Mg /$NaNO_3$/XFS-4008L - EC-MA - DEGDN.
[b]1.25-inch diameter.

SECTION IV

SODIUM NITRATE PARTICLE SIZE EFFECTS

To conduct meaningful composition optimization and also achieve minimum binder levels, effective control of castability is necessary. Previous work had shown that the particle size of $NaNO_3$ has the greatest single effect on castability. It was found that screening dried Lee-Attrition milled $NaNO_3$ through 400 mesh immediately prior to use consistently produced the lowest viscosity. It is believed that $NaNO_3$ exhibits a great tendency to agglomerate or coalesce on storage, a phenomenon that is aggravated by atmospheric humidity.

It also was discovered that the anti-caking agents MgO and Cab-o-sil minimize the rate and extent of coalescence during storage. Therefore, all $NaNO_3$ used in this program contained 0.5 percent MgO and 0.25 percent Cab-o-sil.

A. MIKRO-PULVERIZER

Screening through 400 mesh is tedious and inefficient, and probably is unacceptable for large scale processing. Attempts proved successful to substitute a production type of grinder, the Mikro-Pulverizer, for the preparation of acceptably fine $NaNO_3$. Table V shows that while compositions employing unscreened Mikro-pulverized $NaNO_3$ may be slightly less efficient, burning rate and castability are favorably affected. Screening through 400 mesh appears unnecessary. This technique was adopted for all optimization studies. Anticake agents may be added prior to or after grinding.

In studies aimed at further particle size reduction, $NaNO_3$ with anticake agents was passed twice through the Mikro-pulverizer. This treatment diminished the castability.

Continuing efforts were made to lower binder content by reducing the particle size of $NaNO_3$ and eliminate as much as possible any aggregates. This led to a reevaluation, passing the Mikro-pulverized $NaNO_3$ through a 400-mesh screen in the RO-tap screening apparatus. More rapid screening was obtained, making this possibly an acceptable processing operation. The improvement is due to finer grinding by the Mikro-pulverizer and incorporation of anti-cake agents prior to grinding. Data in Table VI, gathered on 100-g mixes, indicate the relative merits of screening, and the possibility of achieving castable compositions at 19 to 20 percent binder.

B. SODIUM NITRATE DISPERSION

Because reagglomeration of the finely divided $NaNO_3$ occurs upon addition to hydrophobic binder systems, prewetting with surfactants was investigated for possible further reduction

TABLE V. PROCESSING $NaNO_3$

Batch Number	$NaNO_3$ Type	Batch Size (g)	Brookfield Viscosity (cps)	Luminous Efficiency (cd-sec/g)	Burning Rate (in/sec)
Composition A - 50.29/27.71/22.0 - Mg /$NaNO_3$/XFS-4008L - EC-MA - DEGDN					
1942-86	Lee-Attrition (<400 mesh)	500	460,000	39,200	0.056
1942-89	Lee-Attrition (unscreened)	500	430,000	37,700	0.056
1942-87	Mikro-Pulverized 0.032" round hole screen (unscreened)	800	420,000	36,500	0.065
1942-91	Mikro-Pulverized 0.020" HB x 3/64B (unscreened)	800	180,000	36,600	0.062
Composition B - 52/26/22 - Mg/$NaNO_3$/XFS-4008L - EC-MA - DEGDN					
1942-92	Mikro-Pulverized 0.020" HB x 3/64B	800	290,000	38,200	0.066
1942-95	Mikro-Pulverized 0.020" HB x 3/64B	8000	200,000	38,600	0.056

in binder levels. Prewetting $NaNO_3$ with non-ionic Tergitol E-35 proved most efficient, followed closely by non-ionic Dow surfactant 9N4. However, at surfactant/$NaNO_3$ concentrations of 10-15 percent, the quantity necessary for thoroughly wetting $NaNO_3$, there was evidence of incompatibility. Subsequent studies revealed that only 0.5 percent added to the binder reduced viscosity and improved castability consistently and effectively.

TABLE VI. EFFECT OF $NaNO_3$ PARTICLE SIZE ON VISCOSITY

Processing of $NaNO_3$	% Binder	Viscosity 25°C (cps)
Lee Attrition Mill Screened through 400 mesh	22.0	87,500
Mikro-Pulverized No screening	21.0	162,500
Mikro-Pulverized Screened through 270 mesh	21.0	125,000
Mikro-Pulverized Screened through 400 mesh	21.0	90,000
Mikro-Pulverized Screened through 400 mesh	19.0	400,000 to 600,000

Studies shown in Table VII, using the 50/30/20, - magnesium/$NaNO_3$/binder composition, demonstrate the effectiveness of viscosity reduction with Tergitol E-35.

TABLE VII. VISCOSITY REDUCTION WITH TERGITOL E-35[a]

Viscosity (cps)	Tergitol E-35 (%)
240,000	[illegible]
173,000	0.25
145,000	0.50
130,000	0.75
115,000	1.00

[a] 50/30/20 $Mg/NaNO_3$/XFS-4008L - EC-MA - DEGDN.

Because of time limitations, no surveillance stability data were obtained on surfactant-containing formulations. Therefore, surfactants were not utilized in the final optimized composition.

SECTION V

MAGNESIUM PARTICLE SIZE

Particle size variations in commercially available atomized magnesium are common. Earlier studies indicated that an excess of material finer than 100 mesh is undesirable and leads to high viscosity and poor castability at the desired low binder levels. It was recommended that the 40/200 grade magnesium contain a maximum of 15 percent finer than 100 mesh. However, studies with a recently obtained lot of magnesium (PO No. 034273) do not bear out this conclusion. Table VIII shows a screen analysis and resulting comparative viscosities of three 40/200 lots of magnesium.

TABLE VIII. MAGNESIUM PARTICLE SIZE DISTRIBUTION

Mesh No. % on	Lot No. 2097	Lot No. 033992	Lot No. PO 34273
60	31.1	15.1	50.2
80	24.6	31.1	38.3
100	32.2	11.6	6.5
140	4.3	23.0	4.4
200	4.0	16.8	0.3
230	3.0	1.5	0.1
Pan	2.0	--	0.1
Viscosity cps[a]	306,300	>1,000,000	750,000

[a]50/30/20 Mg/$NaNO_3$/binder (XFS-4008L - EC/MA - DEGDN).

Both the coarser PO 34273 and finer 033992 lots lead to high mix viscosities. Because 2097 was in short supply, a study was undertaken to determine the most efficient magnesium particle size distribution for maximum castability by blending the above three lots. Furthermore, because 033992 contained a

broad distribution, it was separated into +100 and -100 mesh fractions to study particle size effects more easily.

The most efficient combination was a 50/50 blend of 2097 and +100 mesh 033992. However, the quantity of 2097 available was insufficient to prepare all the Air Force sample flare candles. It was found that a 65/25/10 ratio of +100 mesh 033992/2097/034273 produces a viscosity of 175,000 cps at 25°C, in a 50/30/20 - Mg/$NaNO_3$/binder composition. When 10 percent magnesium fines (<100 mesh 033992) was added, the data presented in Table IX were obtained. This shows the significant effect of this particle size distribution and of freshly screened $NaNO_3$ on viscosity.

TABLE IX. EFFECTS OF FRESHLY SCREENED $NaNO_3$ AND MAGNESIUM PARTICLE SIZE DISTRIBUTION

	Lot 2097	Blend
50% Magnesium	100%	58.5%, 033992, +100 mesh 22.5%, 2097 9.0%, 034273 10.0%, 033992, -100 mesh
30% $NaNO_3$	Mikro-pulverized	Mikro-pulverized freshly screened
20% Binder (XFS-4008L, EC-MA, DEGDN)	Same	Same
Viscosity, 25°C cps	306,000	185,000

Figure 1 shows the comparative particle size distribution of Lot 2097, the blend which gave minimum viscosity, and the blend shown in Table IX.

On the basis of these studies, it was decided to use the 58.5/22.5/9.0/10.0/magnesium blend and freshly screened Mikro-pulverized $NaNO_3$ for the preparation of sample candles for evaluation at the Air Force Armament Laboratory.

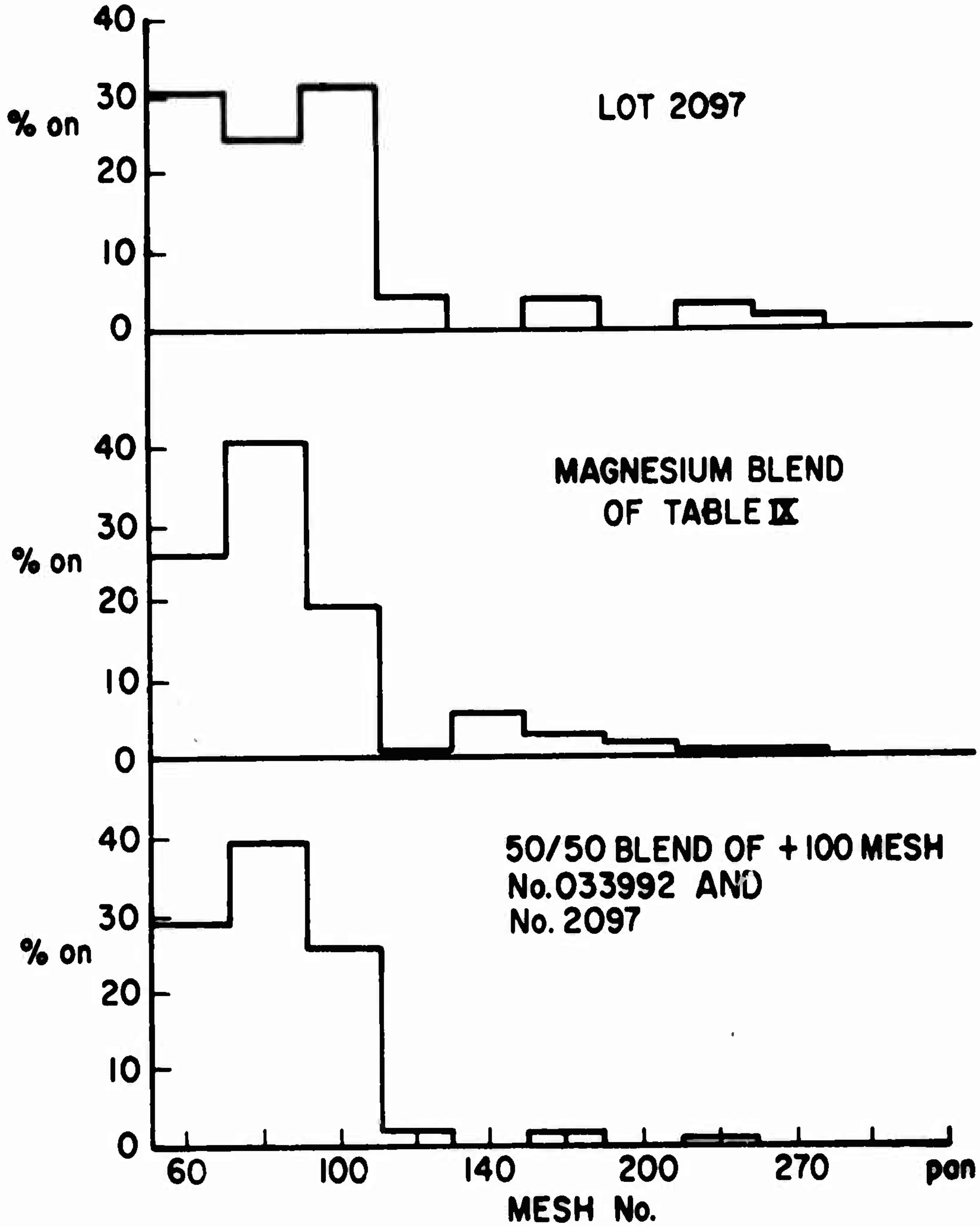

Figure 1. Particle Size Distribution of Magnesium Powders

SECTION VI

COMPOSITION OPTIMIZATION

The compositions shown in Table X result from a composition optimization, conducted in 3.4-inch I.D. Viton®-lined paper-phenolic cases and fired in the inverted position.

At the 20-percent binder level about 50 to 52 percent Mg and 28 to 30 percent $NaNO_3$ appear to be optimum. The 50/30/20 composition was selected for the preparation of sample experimental candles for evaluation by the Air Force because of the higher luminous efficiency in the 3.4-inch diameter candle.

TABLE X. OPTIMIZATION, CAST CANDLES

Comp Number	Composition[a]	Viscosity (cps) 25°C	Burn Rate (in/sec)	Luminous Efficiency (cd-sec/g)
1942-112	52/28/20	275,000	0.061	42,600[b,c]
1942-113	50/30/20	306,000	0.059	45,000[b,c]
1942-117	48/32/20	537,500	0.057	38,400[b,c]
1942-109	52/28/20	275,000	0.066	53,000[d]
1942-110	50/30/20	306,000	0.060	50,800[d]
1942-117	48/32/20	537,500	0.057	37,800[d]
Mark 45 Comp			0.055	55,700[d]
Mark 45 Comp			0.055	53,200[d]

[a] $Mg/NaNO_3$/Binder: Magnesium Lot 2097, 40/200. $NaNO_3$ - Mikro-pulverized, 0.50% MgO and 0.25% Cab-o-sil, unscreened. Binder - XFS-4008L, 27.1%; EC/MA, 37.9%; DEGDN, 35%.

[b] Inverted firing.

[c] 3.4-inch diameter paper-phenolic case.

[d] 1.25-inch diameter paper-tape case.

SECTION VII

SAMPLE CANDLES

A. PRELIMINARY BATCH

A 5,000.0-g batch of composition 1942-110 (Table X) was prepared to study castability and combustion behavior. It contained the magnesium blend shown in Table IX and $NaNO_3$ freshly screened just prior to use.

A very favorable viscosity was obtained for this mix, 185,000 cps at 25°C. A lower binder level might be achieved, with better performance.

B. MARK 24 CANDLES

Mark 24 candles received from Eglin AFB were functioned for purposes of comparison with the best efforts cast flares. Most of these candles were fired in the inverted position. Several of the Mark 24's burned significantly faster than the nominal burning time of 180 ± 10 sec. Most of them broke up and fell to the floor near the end of functioning, the faster-burning ones sooner.

Table XI shows the results on these Mark 24 candles, along with comparative data on the best efforts cast candles. The lot number was undecipherable on many of the Mark 24 candles; it is recorded where available.

The average efficiency of all the Mark 24 candles fired was 27,900 cd-sec/g. If only those with burning times of 170 sec or greater are selected, the average is 29,100 cd-sec/g. The average of the latter group is 30,000 cd-sec/g for inverted firings and 27,400 cd-sec/g for upright attitude. In some firings smoke obscuration was evident. Because of the higher burning rate and greater diameter of the Mark 24 candles, it would be expected that smoke problems would be more severe than for the 3.4-inch cast flares.

The average efficiency for the best efforts cast candles was 40,650 cd-sec/g, 43,400 cd-sec/g for the inverted firings. The average burning rate was 0.057 in./sec. The average intensity was 570,000 cp, 640,000 cp for the inverted firings. These results are considered highly encouraging.

C. SAMPLES FOR AIR FORCE EVALUATION

Based upon these data, thirty 3.4-inch diameter flares were produced in four batches and shipped to Eglin AFB.

TABLE XI. MARK 24[a] AND CAST[b] CANDLES: COMPARATIVE FIRINGS

Candle	Burning Time (sec)	Burning Rate (ips)	Efficiency (cd-sec/g)	Intens (10^6 cp)	Attitude
Mark 24 (lot ?)	177	0.090	32,000	1.46	Inverted
Mark 24 (lot ?)	187	0.085	28,800	1.25	Inverted
Mark 24 (lot ?)	180	0.089	27,700	1.25	Inverted
Mark 24 (lot?)	176	0.091	27,000	1.24	Inverted
Mark 24 (lot 1429)	152	0.105	25,000	1.33	Inverted
Cast,80-1	82	0.057	42,800	0.63	Inverted
Mark 24 (lot 1429)	157	0.102	27,000	1.39	Inverted
Cast,80-2	80	0.059	43,800	0.66	Inverted
Mark 24 (lot ?)	197	0.082	34,000	1.40	Inverted
Cast,80-3	84	0.056	43,600	0.62	Inverted
Mark 24 (lot 1426)	147	0.109	23,900	1.32	Inverted
Mark 24 (lot 1429)	187	0.086	29,900	1.30	Upright
Cast,80-4	90	0.056	32,400	0.43	Upright
Mark 24 (lot 1426)	174	0.092	24,500	1.14	Upright
Mark 24 (lot ?)	182	0.080	27,900	1.30	Upright
Mark 24 (lot ?)	192	0.080	30,300	1.28	Inverted
Mark 24 (lot ?)	158	0.101	24,100	1.24	Inverted

[a]4.25-inch diameter, cardboard case.
[b]3.4-inch diameter, paper-phenolic case.

SECTION VIII

PROCESSABILITY

A. SCALING-UP

Successful scaling-up from 100 g to 400-600 g and then to 5000 to 8000 g batches was accomplished. The viscosities obtained in smaller batch sizes were maintained or improved. No mass effect on cure rate or exotherm was noted in the larger scaled-up batches, indicating adequate pot life at ambient temperatures, irrespective of batch size. Thus, production scale operation should present no difficulties.

B. CURE TEMPERATURE AND VIBRATION EFFECTS ON DENSITY

Because curing at a constant 70°C yielded some variations in flare densities, a study was undertaken to optimize curing conditions. Table XIII indicates that density decreases with higher temperature curing. However, maximum density was obtained with an initial low temperature cure, followed by a post-cure at 70°C. Presumably this contributes to degassing of the mix. In an effort to eliminate the two-temperature cure cycle, it was found that 1/2-hour exposure of cast flares to mechanical vibration produced similar or increased densities.

TABLE XII. EFFECT OF CURING TEMPERATURE ON DENSITY[a]

Composition Number	Curing Temperature (°C)	Density (g/cc)	Burning Rate (in/sec)	Luminous Efficiency[b] (cd-sec/g)
1942-92-1	46	1.60	0.061	44,500
1942-92-3	60	1.53	0.064	43,100
1942-92-5	70	1.47	0.072	45,200
1942-95-7	45-70	1.69	0.056	44,800
Mark 45 Composition	70	1.70	0.060	51,200

[a]Composition - 52/26/22 - Magnesium/$NaNO_3$/Binder (XFS-4008L - EC-MA - DEGDN).

[b]1.25-inch diameter tape-wrapped candles.

C. HAZARDS STUDY

The final mix temperature of 24.5°C in an 8,000 g mix indicated a safe minimal exotherm on mixing. In a curing exotherm test, a 3.4-inch diameter by 4-inch long cast flare displayed a mild and easily controllable exotherm of 7.0°C for approximately 15 to 20 minutes.

A DTA trace of an uncured mix is shown in Figure 2. It exhibits no exotherm until above 150°C and an ignition temperature above 300°C.

Using the Olin drop weight tester, the impact sensitivity, E_{50}, was found to be 280 Kg-cm.

In standard explosive booster tests, using 10 g of C-4 and a No. 6 blasting cap, no detonation could be propagated. This test was done on a 117 g 1.25-inch diameter candle in a paper-phenolic case, a 232 g 1.7-inch diameter candle in a fish-paper case, and an approximately 260 g 1.85-inch diameter candle with no case.

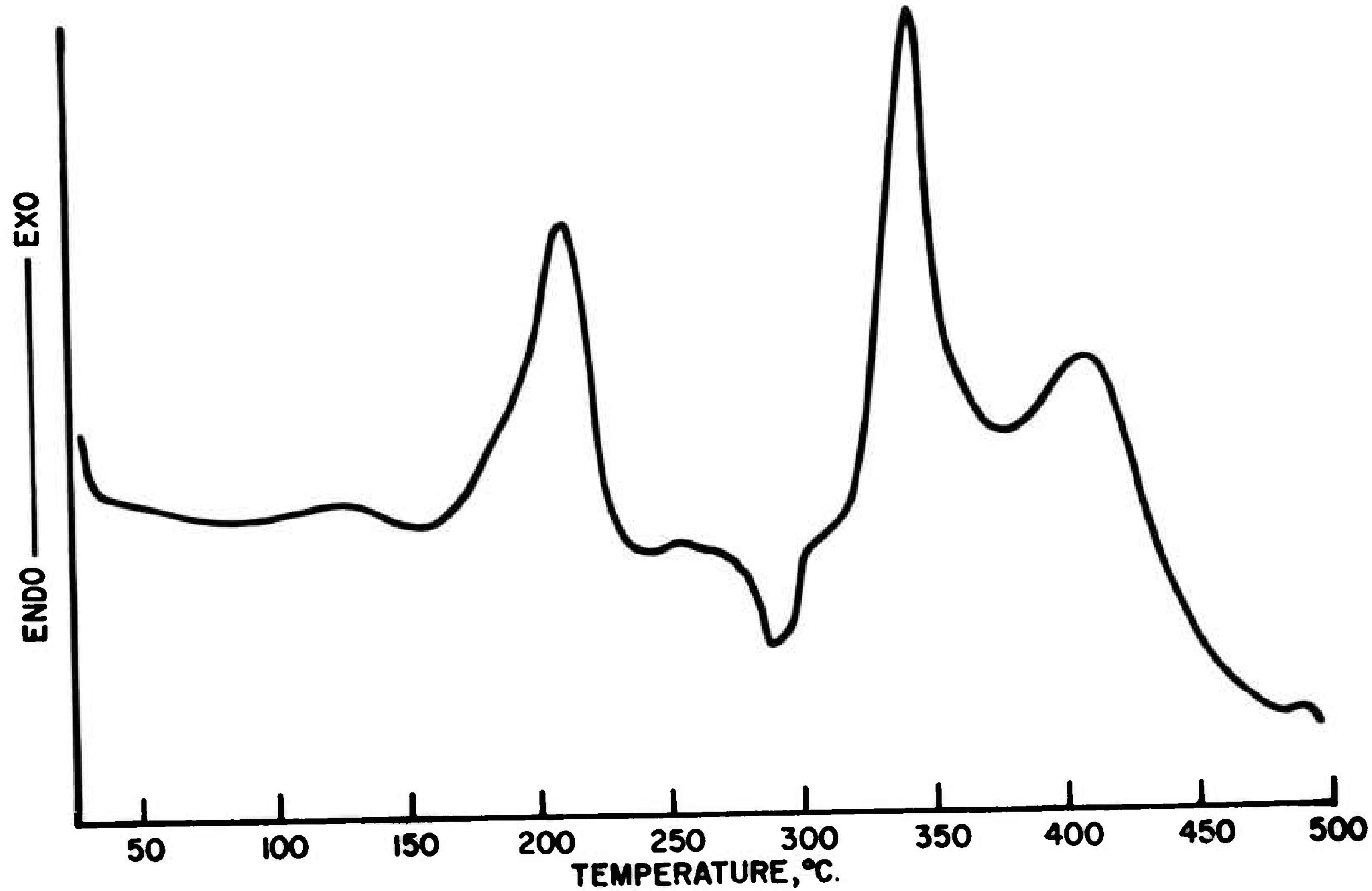

Figure 2. Differential Thermal Analysis of Best Efforts Mix

SECTION IX

NEW BINDERS

A. POLYESTERS

Several experiments used oxygen-rich vinyl esters formed from unsaturated olefins. Resins were studied of ethylene glycol (EG) (52 percent oxgyen) and MA (49 percent); hydroxyethyl acrylate (HEA) (41 percent oxygen) and MA; and HEA, MA, and allyl diglycol carbonate (ADGC) for crosslinking purposes. These appeared promising in neat binder studies, but complete compositions displayed high exotherms, gassing, and decomposition during mixing and curing. Reaction of Mg with carboxyl groups in the presence of water of esterification was presumed responsible.

A more promising system was homopolymerized ADGC or its copolymer with MA. Flare compositions based on this binder seemed compatible, and relatively high oxygen content (42 to 44 percent) was attainable. Of even more interest was Dow experimental material Tex-R-1939, the diacrylate of bishydroxyethyl carbonate (43.5 percent oxygen).

B. TEX-R-1939

1. Investigatory Studies

Because Tex-R-1939, when used as a primary binder component, displays excellent wetting qualities, good pot life, a high level of compatibility, and rapid cure rate at elevated temperatures, considerable effort was directed toward its development.

Free radical initiators MEK peroxide, cumene hydroperoxide, and lauroyl peroxide were found to catalyze homopolymerization of Tex-R-1939 efficiently. A 0.3 percent concentration of lauroyl peroxide is recommended for curing at 70°C.

Initial studies of unplasticized 10-g mixes indicated that a 1:1 mole ratio of Tex-R-1939 to MA, with FC added in a quantity equal to the MA (for higher oxygen content), resulted in a promising composition containing 24 percent binder. The viscosity was very low (<100,000 cps, at 25°C), and the polymerization rate and exotherm were easily controllable. Grain integrity appeared excellent with no evidence of expansion or doming during cure. However, subsequent studies with larger mixes gave low luminous efficiency. For example, at 17.4 percent binder, with no nitrate ester plasticizer, approximately 34,000 cd-sec/g efficiency was obtained at a burn rate of 0.070 in./sec. Attempts to increase oxygen content by incorporating tartaric acid (64 percent oxygen) proved detrimental to grain integrity. Co-curing with XFS-4008L

for increased cross-link density also failed to improve luminous efficiency. The same was true of allyloxypropyl glycidyl ether, (AOPG) when copolymerized with Tex-R-1939 and MA.

Since it appeared that an acceptable efficiency level could not be reached without a nitrate ester plasticizer, work was begun on TEGDN plasticization of a homopolymerized Tex-R-1939 binder. These compositions produced excellent viscosities, ranging from 37,500 to 55,000 cps at 25°C with TEGDN levels of 0 to 40 percent of the binder. Interestingly, all the candles containing TEGDN, even 40 percent TEGDN, displayed very dry surfaces, indicative of the high plasticizer tolerance capacity of Tex-R-1939. An efficiency of 38,300 cd-sec/g was obtained with 40 percent TEGDN plasticizer content. Additional studies, shown in Table XIV, revealed that 47,000 cd-sec/g, luminous efficiency and favorable burning rates can be achieved with 40 to 50 percent TEGDN or DEGDN levels. Initial data indicate that the 52/28 ratio is an approximate optimum for the Mg/$NaNO_3$ ratio.

TABLE XIII. COMPOSITIONS CONTAINING TEX-R-1939

Ingredient	Percent Composition				
Mg	49.0	52.0	49.0	52.0	52.0
$NaNO_3$	27.0	28.0	31.0	28.0	28.0
Tex-R-1939	14.4	12.0	12.0	10.0	10.0
TEGDN	9.6	8.0	8.0	10.0	--
DEGDN	--	--	--	--	10.0
Lauroyl Peroxide	0.2	0.2	0.2	0.2	0.2
Binder	24.0	20.0	20.0	20.0	20.0
Plasticizer in Binder	40.0	40.0	40.0	50.0	50.0
	Performance				
Viscosity, cps 25°C	52,500	500,000	220,000	245,000	265,000
Burn Rate, in/sec	--	0.067	0.064	0.071	0.082
Luminous Efficiency, cd-sec/g	38,300	45,000	38,200	45,200	46,800

2. Surveillance

These compositions show a slight surface softness at the 50 percent plasticizer level, possibly indicating over-plasticization. A duplicate 500-g batch prepared for surveillance studies (Table XV) gave no indication of migration or incompatibility at a slightly higher (0.30 percent) catalyst content. Thus it appears that more than 50 percent DEGDN or TEGDN could be tolerated. These surveillance data reveal that a composition based on Tex-R-1939 - DEGDN binder shows promising surveillance stability. Weight loss is acceptably low. Combustion data (representing only one candle) show varying luminous efficiency values. It is believed that this reflects observed varying chimney effects and side burning, rather than composition degradation.

TABLE XIV. SURVEILLANCE OF TEX-R-1939 - DEGDN BASED COMPOSITION[a]

Parameter	Days at 70°C			
	0	10	24	31
Weight Loss, %	--	0.18	0.17	0.14
Color and Integrity	--	No Change		
Plasticizer Exudation	--	None Detected		
Ignition		Immediate		
Lum Eff, cd-sec/g[b]	40,600	36,200	26,700	31,650
Burn Rate, in/sec[b]	0.082	0.077	0.084	0.082

[a]Magnesium, 51.6%; $NaNO_3$, 28.4%; Tex-R-1939, 10.0%; DEGDN, 10.0%.
[b]Single candles.

Safety tests showed an impact sensitivity (E_{50}) of 280 kg cm for the composition with 20 percent TEGDN in the binder. At 30 and 40 percent TEGDN, values of 251.0 and 218.0 Kg cm were obtained, respectively. It can be predicted that (E_{50}) for the 50 percent TEGDN composition will fall in the range of 150 to 200 Kg cm.

3. Other Additives

The curing agents D.E.H.®[1] 20 (diethylenetriamine, DETA) and ethylenediamine (EDA) were investigated at low binder level in Tex-R-1939 compositions, because of their ability to solubilize $NaNO_3$. A very rapid exothermic cure was obtained, indicative of amine-double bond copolymerization with Tex-R-1939.

The plasticizer DEO (diethyl oxalate) was studied in an attempt to confirm a promising data point obtained during an earlier program. It was found to give poor luminous efficiency in compositions containing XFS-4008L - MA and XFS-4008L - EC-MA binders. Therefore, work was not pursued in Tex-R-1939 binder systems.

Substitution of the reactive diluent allyl glycidyl ether (AGE) for DEGDN in a Tex-R-1939 - D.E.H.® 24 binder system yielded castability at 17.5 percent binder level. However, combustion properties were very poor.

Substitution of Dowanol®[2] EM (ethylene glycol methyl ether), a $NaNO_3$ solvent, for DEGDN in the XFS-4008L - EC-MA - DEGDN binder system resulted in incompatibility. However, it proved compatible in diamine cured epoxy systems. A first attempt resulted in a castable mix at 15 percent XFS-4008L - AGE - D.E.H.® 24 - Dowanol® EM binder, using 30/50 magnesium.

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[1]D.E.H., a trademark of The Dow Chemical Company for epoxy curing agents.

[2]Dowanol, a trademark of The Dow Chemical Company for glycol ethers.

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SECTION X

CONCLUSIONS AND RECOMMENDATIONS

The best efforts cast candles in 3.4-inch paper phenolic cases give very promising performance. They are superior in efficiency to the Mark 24 candles tested, although it is felt the latter suffered from poor reproducibility, case bond failure, and tunnel smoke problems. In 1.25-inch taped cases, the best efforts cast composition is nearly equivalent to the Mark 45 composition. Thirty 3.4-inch flow-cast candles have been furnished to Eglin AFB. Results obtained from firing these items will give a better comparison of the flow-cast candles with standard pressed candles.

No surveillance work has been done on 3.4-inch cast candles in paper-phenolic cases. It is recommended that some of the sample candles supplied to Eglin AFB be stored at 70°C for 1 to 4 weeks and then functioned.

Results on 1.25-inch fish-paper cases were encouraging. Cast 3.4-inch candles should be tested in these cases.

It was shown that mix viscosity can be reduced by employing surfactants. Since no time was available for surveillance of such a composition, however, it was not used in the best efforts flares. A 28-day storage test at 70°C should be performed. If these candles prove stable, further optimization work should be done on the low viscosity mix. Binder level can be reduced to the limit of castability. The $Mg/NaNO_3$ ratio should then be readjusted to maximize efficiency within the constraints of flow castability.

Considerable work was done on Mg particle size distribution during this program. However, the acceptable limits on this parameter have not been established fully. This type of effort is time-consuming, but it should be pursued.

Two polyester binders studied during this program merit further effort. A minimum of work was done on ADGC and ADGC with MA or EC-MA. This research should be carried forward. Compositions based on Tex-R-1939 appear very desirable. High temperature surveillance tests should be run on compositions with Tex-R-1939 binders plasticized with DEGDN and with TEGDN . This type of composition should be scaled to 3.4-inch candles and the composition optimized. As a part of this program, a sample of Tex-R-1939 has been supplied to Eglin AFB for further formulation work.

Because of the promise of flow-cast compositions shown during this program, flow-cast mixes should be considered for any new illumination items and as an alternate for current flares.

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13. ABSTRACT

Previous work (Contract F08635-70-C-0028, Eglin Air Force Base) gave encouraging results for flow-cast illumination flares. The present development effort has resulted in compositions comparable in performance with pressed mixtures. Viton®-lined paper phenolic cases have proved satisfactory in 3.4-inch-diameter size. The agglomeration of sodium nitrate can be reduced by the addition of MgO and Cab-O-sil. However, the oxidizer also should be used immediately after grinding to avoid agglomeration. Surfactants can be used to improve mix viscosity. The particle size distribution of magnesium used is critical to mix viscosity and luminous efficiency. With 20 percent binder in the mix, maximum performance is obtained at about 52 percent Mg for 1.25-inch candles and 50 percent Mg for 3.4-inch candles. The best efforts formulation contains 50 percent of a 40/200 mesh Mg blend, 30 percent $NaNO_3$, and 20 percent of XFS-4008L - EC-MA - DEGDN binder. In 3.4-inch candles it yields 43 to 45,000 cd-sec/g efficiency at 0.056-0.059 in./sec burning rate. This mix has been scaled up to 10-kg batch size. Further work has also been accomplished on new binders. The most promising is based on a vinyl ester, Tex-R-1939, plasticized with DEGDN.

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Flow casting						
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MILITARY PYROTECHNICS.

This handbook is issued with the understanding that it shall at all times be given the care accorded confidential information; that no portion of it shall be published by paraphrase or otherwise, and that it shall be returned to the office of the Chief of Ordnance when the person to whom it is issued leaves the military service of the United States.

The facts have been collected by W. N. Dickinson from the official records, cablegrams, and reports, and have been supplemented by information obtained from officers in the several branches of the military establishment, whose services were rendered both in the United States and with the American Expeditionary Forces.

The matter included in the present pamphlet was originally compiled in conjunction with the "History of Trench Warfare Matériel" and references to it will be found in that history.

For convenience in publication and in use, it has been separated into the present form.

C. C. WILLIAMS,
Maj. Gen., Chief of Ordnance, U. S. A.

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PHOTOGRAPHS.

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MILITARY PYROTECHNICS.

Chapter I.

PYROTECHNICS.

Military pyrotechnics are employed for communication and illumination.

In the former of these two uses, they play their part in the great system of understanding on the basis of which modern warfare is waged. While included within the trench warfare matériel, pyrotechnics are employed also in open warfare, and both from the ground and from planes in the air.

In an unobtrusive corner in the National Museum in Washington is a large war map, brilliantly lighted and confronted by four conference chairs. On this map are lines and tabs indicating the entire Western Front with the positions of the several armies on both sides of the line at the time of the signing of the armistice. Indicated thereon are the headquarters, the reserve units, and the distribution of the troops on the fighting front by divisions. This represents the concentration of information as to the disposition of the various divisions, as obtained by telegraph, telephone, and by dispatches.

Apart from the reserves, it represents the information which was constantly being gathered through the intermediate channels from the fighting front. This front might consist of long lines of trenches, open country, woods, mountains, or waterways. The front might be quiet or in vigorous action, and the difficulties of establishing and maintaining contact for immediate communication varied with the degree of action, with weather conditions and the time of night or day. In time of movement instant information was of the utmost importance. On it depended the opportunity for surprise, knowledge of the need for support or the necessity for change in plans. Battle without chaos is dependent upon complete understanding and it is this understanding only which prevents chaos. The information to establish this understanding was conveyed by ground telegraph, wireless telegraph, telephone, buzzerphone, written dispatches, messengers on cycles and motor cycles, Cavalry riders, runners, electric flashlights or other lights or projectors using either intermittent flashes or color, reflection of the sun in mirrors, whistles, horns, bugles, message grenades, flag signals, arm movements, dogs, carrier pigeons, photographs, messages dropped from airplanes, panels laid on the ground and observed from airplanes, and pyrotechnics.

It was necessary that the information be transmitted from the front to the rear, from the rear to the front, and laterally between units cooperating in the same action. Observation posts, balloons, airplanes, and practically every part of the field were involved in this necessity for communication. Reliance could not be placed upon one method only of communication, as any one method might be rendered impotent. Wires might be cut, a balloon or an airplane brought down, messengers killed or cut off, and observation posts destroyed. One of the principles in warfare is that an observation post which is not fired upon is not necessarily one which has not been located. It is indeed considered best to leave unmolested stations which have been located in order that the enemy may not construct others better protected or disguised. It often happens that these stations are not destroyed until the day when it will be really advantageous to deprive the enemy of their use, as in the case of attack.

In the forward areas a complete understanding must exist between each Infantry unit on the front and its supporting Artillery, the Air Service, Trench Mortar batteries, the Chemical Warfare units, the sappers who are about to explode mines, and with the plans and operations of the units immediately adjoining. As actions are now planned and carried out, the establishment of uniform time for the setting of watches to permit of the carrying out of orders on exact schedule is of the utmost importance. With troops widely scattered through a labyrinth of trenches, shell holes, woods, ravines, and protected positions, this establishment of time must take place, in so far as possible, from a single source and at a moment sufficiently close to the major operation to reduce to a minimum any errors resulting from variation in the functioning of individual timepieces. If this complete understanding is not had, units fail to cooperate or may be subjected to the fire of their own artillery, or the artillery, machine gun, or mortar fire of adjoining units.

This whole subject of communication and intercommunication is treated broadly under the tactical instructions in "Liaison for all Arms."

Pyrotechnics are visible (more or less) either by night or by day, with the exception that those with yellow or red smoke and flag rockets can not always be seen to advantage at night. Their meaning may be conveyed by the form, color, or numerical distribution of burst. When used as ground signals it will be observed that they are more liable to be employed in the very forefront of the action at a time when seconds count and when the lives of many men or the success of an individual movement depends upon their proper functioning. When it is recalled that these pyrotechnics when in the possession of forward units may be carried through trenches knee-deep in water, through a deluge of rain, or across marshy country, it

will be clear that their protection from dampness is imperative. They may be fired at night, and more frequently are fired at night than by day, and their distinguishing markings therefore should be readily determinable by touch as well as by sight. One signal means one thing and another signal means another thing, and the wrong signal would convey incorrect information and cause confusion and might bring disaster. Protection from dampness and clear marking are features to be dwelt upon.

Signal rockets may be sent up from carefully aimed troughs or tubes, or may be sent up without fixtures of any kind, and a difference in the course of the rocket might bring the burst over a unit different from that by whom it had been discharged, or at a point which would cause confusion in the mind of the watcher as to the unit to which the signal applied. For this reason it was necessary in our own pyrotechnics to take a lesson from the French and attach a smoke tracer to rockets, which, while it lessened the height to which the rocket could be thrown, indicated the source from which the rocket had been sent.

The question of height also has a bearing upon the chance of confusing the signals discharged from ground units and from airplanes, which may burst along substantially the same line of front, but whose meaning is intended for different watchers and for different purposes, hence the establishment of different altitudes of burst for ground and airplane signals.

When friendly and enemy front lines are in close proximity, it is manifestly difficult and frequently impossible for watchers to determine whether rockets sent up have emanated from a friendly or from an enemy source, and hence the frequent change in the types of rockets employed by troops on different nights.

Under favorable conditions, ground pyrotechnics may establish an understanding with friendly airplanes or artillery, indicate position of units which may or may not be cut off from other means of communication, call for a barrage, give warning of a gas attack, indicate that ammunition is running low, that friendly artillery shell are raining on our own troops, or convey practically any other information that may be agreed upon in the code.

From the trenches where the ground signal pyrotechnics were most frequently employed, apart from establishing communication with airplanes and lining out the position, their use was practically confined to signaling from the front to the rear, and the code was finally confined to very few signals. This was due to the uncertainty in the determination of the unit from which the signal emanated, the lack of certainty of proper functioning of the signal as a result of chemical or physical changes in the signal, and the practice of the enemy of observing the signal and then repeating that signal at

different parts of his or near-by lines for the purpose of confusing our signal officers. Military pyrotechnic signals have a place, but for use along an entrenched front with the enemy close at hand there are distinct practical limitations to their employment.

While the outline of forward positions is perhaps more frequently indicated by means of panels laid upon the ground and observed by friendly airplanes, such outline of position may be indicated by the burning of Bengal flares—position lights—or by the use of signal cartridges discharged from Very pistols or VB signal projectors employed with rifles.

Pyrotechnics also have their use in providing a sudden illumination at night over an area which it is desired to guard against surprise attack or in revealing an enemy who may be effecting a movement or operation under the cover of darkness.

Smoke torches, which also come under the head of pyrotechnics, may be employed for concealment of the movements or operations of friendly troops.

Military pyrotechnics are also employed largely in the air service for the direction of planes, the establishment of communications with forward ground units or with watchers, for purposes of illumination, for the establishment of understanding with the home field as to whether it is clear for night landing, and by means of wing tip flares for providing temporary illumination of the ground at night to permit of landing.

For use from airplanes the signals usually are discharged from Very pistols, and frequent use of the Very pistol is also made in discharging pyrotechnic signals from the ground.

GENERAL NARRATIVE.

Prior to the present conflict, the following pyrotechnics had been developed for the United States Army: Rockets by the Signal Corps; position lights by the Engineering Corps; Frankford Arsenal rifle illuminating grenades by the Army Ordnance Department; and the Very pistol cartridge, which was in production by the Navy and which had been issued in very limited quantities to the Signal Corps of the Army.

The rockets employed by the Signal Corps were red, green, white, yellow smoke, and sequence rocket (since discarded), all with parachute. The comparatively small elevation attained by these rockets was between 200 and 400 feet, and the colors were indistinct and the functioning uncertain.

The white hand position light, which had been developed by the Engineering Corps, would burn for about one minute with a candlepower of 12,000.

The Frankford Arsenal rifle grenade, illuminating, was both unsatisfactory and costly.

The Very pistol cartridge, manufactured by the Navy and issued in small quantities to the Signal Corps, was No. 10 gauge. About 3,000,000 cartridges had been manufactured, and hence the manufacturers were in possession of the necessary molds and had obtained experience in producing the Very star. The formula of the composition used by the Navy was not, however, considered stable by the Army Ordnance Department, and the degree of visibility of the cartridge was regarded as unsatisfactory.

In addition to the above there had been more or less developed a smoke torch for signaling purposes, a 35-millimeter cartridge for purposes of aviation signaling, the airplane flare, and the wing tip flare.

In the design of the smoke torch, the British type had been followed and some minor changes made to meet the requirements of the American chemical market.

The 35-millimeter cartridge and its pistol were adopted from the French program and included a variety of signals which were to be used in the Aviation Service.

The airplane flare was to be used from an airplane, illuminating the underlying terrain, and required much experimental work. The type was a slightly modified French Michelin flare.

The wing tip flare is attached to the wings of an airplane, and is used as an illuminant to facilitate night landing. It takes its name from its location on the lower side of the wings of an airplane. The origin of the design was the Holt landing flare adopted by the British.

It will appear that pyrotechnics were to be furnished both for ground work and for the Air Service.

For the use of American troops in France, the early supply of pyrotechnics was obtained abroad.

It was not until September 27, 1917, by General Order No. 128, that the design of all signaling and illuminating devices of a pyrotechnic nature was assigned to the Army Ordnance Department.

On March 28, 1918 (cablegram 796–5H), Gen. Pershing cabled directing that the entire French system of pyrotechnics be adopted. The following signals were therefore adopted:

Signal star rocket, Mark I, white, 1, 3, and 6 stars	2 pounds, 20 inches long.
Signal star rocket, Mark I, red, 1, 3, and 6 stars	
Signal star rocket, Mark I, green 1, 3, and 6 stars	
Signal parachute rocket, Mark I, red	
Signal parachute rocket, Mark I, green	
Signal parachute rocket, Mark I, white caterpillar	
Signal parachute rocket, Mark I, red caterpillar	
Signal parachute rocket, Mark I, green caterpillar	
Signal parachute rocket, Mark I, yellow smoke	
Signal parachute rocket, Mark I, flag	
Signal parachute rocket, Mark I, red smoke	
Signal illuminating rocket, Mark I, white parachute	

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VB star cartridge, Mark I, white, 1, 3, and 6 stars	4½ inches to 7 inches long; 0.7 to 0.9 pound.
VB star cartridge, Mark I, red, 1, 3, and 6 stars	
VB star cartridge, Mark I, green, 1, 3, and 6 stars	
VB parachute cartridge, Mark I, white	
VB parachute cartridge, Mark I, red	
VB parachute cartridge, Mark I, green	
VB parachute cartridge, Mark I, white caterpillar	
VB parachute cartridge, Mark I, red caterpillar	
VB parachute cartridge, Mark I, green caterpillar	
VB parachute cartridge, Mark I, yellow smoke	
Very star cartridge, Mark I, 25-mm., white, 1, 3, and 6 stars	6 inches long; 0.2 to 0.4 pound.
Very star cartridge, Mark I, 25-mm., red, 1, 3, and 6 stars	
Very star cartridge, Mark I, 25-mm., green, 1, 3, and 6 stars	
Very parachute cartridge, Mark I, 25-mm., white	6 inches long; 0.4 pound.
Very parachute cartridge, Mark I, 25-mm., red	
Very parachute cartridge, Mark I, 25-mm., green	
Very parachute cartridge, Mark I, 25-mm., white caterpillar	
Very parachute cartridge, Mark I, 25-mm., red caterpillar	
Very parachute cartridge, Mark I, 25-mm., green caterpillar	
Very parachute cartridge, Mark I, 25-mm., yellow smoke	
35-mm. signal cartridge, Mark I, aviation, white, 1, 2, 3, and 6 stars	4 inches to 6 inches long; 0.5 to 0.6 pound.
35-mm. signal cartridge, Mark I, aviation, red, 1 and 6 stars	
35-mm. signal cartridge, Mark I, aviation, white caterpillar, parachute	
35-mm. signal cartridge, Mark I, aviation, yellow smoke, parachute	
35-mm. signal cartridge, Mark I, aviation, yellow, 1 and 6 stars	
35-mm. signal cartridge, Mark I, aviation, message	
35-mm. signal cartridge, Mark I, aviation, red smoke, parachute	
35-mm. signal cartridge, Mark I, aviation, changing color—red to green	
35-mm. signal cartridge, Mark I, aviation, changing color—red to white	
35-mm. signal cartridge, Mark I, aviation, changing color—green to red	
35-mm. signal cartridge, Mark I, aviation, changing color—green to white	
35-mm. signal cartridge, Mark I, aviation, changing color—white to red	
35-mm. signal cartridge, Mark I, aviation, changing color—white to green	
35-mm. signal cartridge, Mark I, aviation, green, 1 and 6 stars	
Wing tip flare, Mark I, white and red	4 inches long, 0.6 pound.
Airplane flare, Mark I	4 feet long, 36 pounds.
Position light, Mark I, white, ground	3 inches long, 0.4 pound.
Position light, Mark I, red, ground	
Position light, Mark I, green, ground	
Position light, Mark II, white, hand	10 inches long, 0.8 pound.
Smoke torch, Mark I	6 inches long, 0.4 pound.

35-mm. signal pistol, Mark I, aviation	10 inches long, 2 pounds.
Very signal pistol, 25-mm., Mark IV	8 inches long, 2 pounds.

The adoption of the French pyrotechnic system necessitated the change from the No. 10 gauge Very pistol to the 25-millimeter Very pistol.

On April 1, 1918, a letter from the Trench Warfare Division of the American Expeditionary Forces specified the quantity requirements as then viewed to complete the year 1918. In this letter appeared the statement:

> Negotiations are in progress for the purchase from the French of six months' supply from April 1, and the indications are that our demands will be granted and that a further supply sufficient for the balance of the year will also be available from the French if it should be necessary.

Following the decision to adopt the entire French system of pyrotechnics, the preparation of drawings and specifications for manufacture in the United States to correspond with the French system of pyrotechnics was delayed due to the lack of information in the United States of the French requirements of design and details of manufacture. No French drawings nor specifications, and but few samples had been received. Following a number of requests, further samples were received and drawings and specifications were completed shortly thereafter.

Until the middle of the summer of 1918, the status of the pyrotechnic supply program was considered satisfactory. However, during August and September of 1918, the new requirements to June, 1919, were issued, and it became immediately evident that existing facilities were inadequate to produce the large quantities required, involving some 128,000,000 pieces, to be delivered at the rate of approximately 430,000 per diem.

A survey of production possibilities was made, and, based upon the results, the Trench Warfare Board submitted recommendations to the Chief of Ordnance on September 26, 1918, covering the development of the existing private plant facilities in the United States to handle the more complex pyrotechnic items and the erection of Government plants to manufacture the simpler items. The armistice was signed before these recommendations were approved. The Plant Facilities Section also considered the erection of two or more pyrotechnic assembly plants.

In anticipation of the approval of the above recommendations, and realizing the urgent necessity for experienced pyrotechnic operators, the Plant Facilities Section established the Ordnance Pyrotechnic Schools in New York under the direction of Henry B. Faber. Student units were established at the various pyrotechnic factories and extensive research and development was undertaken.

It was not until after this latter date that the Chemical Research Branch of the Trench Warfare Section was established—on October 24, 1918. The lateness of this date will indicate the condition with respect to the scientific treatment of the pyrotechnics problem. At that time it was stated that the most pressing problem for the consideration of the Chemical Research Branch was that of suitable specifications for the chemicals to be employed in the manufacture of military pyrotechnics. It appeared that no work of this character had been previously undertaken by anyone connected with the Ordnance Department and investigation and inquiry soon developed that neither the British, French, nor Italian military authorities had made such study.

Apparently the first logical step was to consult with the manufacturers of pyrotechnics and to use the information thus obtained for the formulation of a tentative draft of specifications to tide over the pressing emergency. It was planned that an extensive chemical investigation should be made with respect to each chemical having a part in the manufacture of pyrotechnic material to ascertain the degree of purity required, the amount of moisture permissible, and the best degree of fineness in grade.

Visits were made to several of the more important plants which were manufacturing pyrotechnic material for the Government and conferences were held with the men best qualified to give information. It was plainly evident that none of the fireworks manufacturers had a real chemical control of their manufacturing processes. At one or two plants some slight attempt was occasionally made to exercise some degree of chemical control, but, inasmuch as none of the manufacturers purchased their chemicals on specifications or appeared to understand the chemistry involved in the functioning of the finished product, such attempts were naturally not fruitful. It was stated by one of the most intelligent men interviewed that he always tested the chemicals by tasting them.

It was the practice of each fireworks manufacturer to buy his chemicals from the same source year after year; his only specification was that the chemical in question "must be the same as that previously furnished." It appears that the manufacturers of the chemicals had learned to know the needs and idiosyncrasies of each of their clients among the fireworks manufacturers and had supplied different grades of material to the different fireworks manufacturers although the chemicals were to be used for the same purpose by each.

The need for chemical control in the manufacture of military pyrotechnics was illustrated by a concrete example: Previous to the war, arsenic disulphide, known in the trade as "red Saxony arsenic" and used for the production of yellow smoke, was imported from Europe. The war resulted in the cutting off of importation and the

use of domestic material became necessary. Trouble at once developed. It was found that to obtain a given volume of smoke, the employment of about 50 per cent more of the chemical was necessary, but why this increase was necessary was not known to the fireworks manufacturers. Trouble of another and very serious nature developed. The workmen using material frequently became badly poisoned. In spite of this, no case had developed in which a chemical analysis was resorted to by the fireworks manufacturers. An Army Ordnance Department chemist made an analysis of the material and found that it contained from 45 to 50 per cent of white arsenic (arsenic trioxide), while the "red Saxony arsenic," formerly employed, and which had been obtained from abroad, was a naturally occurring mineral (realgar), was very pure, and only required grinding to the proper degree of fineness in order to suitably prepare it for its purpose.

The greatest difference of opinion was encountered as regards the permissible quantity of various impurities in the chemicals. Apparently no detailed study of tolerances had been made. It was well known that the presence of small quantities of sodium salts was very harmful in strontium or barium salts, as the yellow produced by the incandescent vapor of metallic sodium degrades other colors: but the actual quantity which was permissible without serious degradation of color was not known. The same may be said regarding the presence of calcium strontium salts or of calcium and strontium in barium salts. The question of the permissible amount of moisture was also one which required more adequate information. All fireworks manufacturers were agreed that moisture should be avoided, and some of them specified that the chemicals furnished them should be dry; yet upon receipt the kegs were opened and allowed to stand open in a humid atmosphere possibly weeks before using. To offset the influence of the atmospheric moisture taken up by the chemicals, it was the practice of the mixer to add other ingredients. At some of the plants the chemicals were kept dry, or were dried before mixing. and the resulting products from these plants were much more uniform in quality.

The moisture content of the chemicals is naturally dependent on the hydroscopicity of the salt itself or of the impurities contained therein. This again brings up the question of allowable impurities For example, a quantity of calcium chloride, which might have no serious effect on the color produced by a strontium salt, might make the mixture so hydroscopic as to render it practically useless. Calcium and magnesium salts, because of their hydroscopic nature, are especially to be avoided and are impurities which are likely to occur in the other salts used. Detailed studies as to the tolerances with respect to these impurities have not been made.

The next question which engaged attention was that of the possibility of substitution or provision for choice of material for use in the manufacture of pyrotechnics with a view to reducing cost and providing against embarassment in the event of a scarcity of some element developed. The highest grade of shellac is costly and if it developed that a lower grade could be used to equal advantage, considerable saving would be effected. The function of shellac is to furnish a suitable binder and control the rate of combustion. The heat produced volatilizes and dissociates the salts which give color to the flame. The shellac employed must necessarily contain no substitutes which would degrade the color of the flame. Some years ago, the Board of Explosives forbade the use of chlorate and shellac mixture in the manufacture of railway fuzes, believing them to be dangerous. This mixture is used together with flame coloring material in position lights, etc., and some of the fireworks manufacturers did not concur in the opinion held by the Board of Explosives. The manufacturers of railway fuzes used mixtures of potassium perchlorate and sulphur in place of chlorate and shellac. Inquiry developed that the immediate substitution of perchlorate would be impossible for a large pyrotechnic program but that the production of perchlorate could be rapidly increased.

But one concern in the United States was manufacturing this material in quantity and practically its whole production was being used by the manufacturers of railway fuzes. While within a few months the production of perchlorate could be increased to provide practically any quantity desired, it was found that extended study should be made first as to the necessity and desirability of the substitution of the perchlorate mixture.

Specifications were compiled and were regarded as being sufficiently rigid for the use of chemicals to be used for military pyrotechnics. Conference with the manufacturers of chemicals led to the belief that the specifications as laid down were reasonable and that no particular difficulty would be encountered in obtaining material of the required purity.

Reference was made to work done by the Chemical Warfare Service at the American University in connection with the signal smokes which had been developed by them and which were believed to be particularly good.

The pyrotechnic schools were disbanded November 30, 1918, but Mr. Faber, with a small corps of assistants, continued the preparation of records of the investigation and work done by engineers and students, and a file of valuable data relating to plant facilities, types of factories, development of and references to formulæ is on file in the Trench Warfare Section for future reference. (File 319.12/17.)

The feeling was expressed that the whole question of military pyrotechnics was one deserving of scientific development. No ex-

tensive research along these lines had been conducted and completed, and the expressed opinion considered the advisability of a Government pyrotechnic laboratory and arsenal to permit of the many problems involved being studied and the solutions embodied in definite drawings and specifications.

A large work of three volumes on pyrotechnic production is now nearing completion.

While the requirements had been very largely increased during August of 1918, a still further increase in these requirements had later been estimated, and the requirement sheets embodying these later increases were about to be issued just as the armistice was signed.

The following table will indicate the requirements in force as of the date of the signing of the armistice and data with reference to the major items of pyrotechnics available then and later:

Principal items in pyrotechnics.

Item.	Total requirements.	Requirements to Nov. 1, 1918.	Ordered in the U. S.	Ordered from abroad.[1]	Floated from U. S.	Completed in U. S. to Nov. 11, 1918.	Total completed in U. S.
Rockets, signal star, Mark I:							
White, 6 stars	1,145,186	363,563				[2] 437,101	
3 stars	1,144,009	362,386					
1 star	1,144,009	362,386					
Red, 6 stars	1,145,186	363,563					
3 stars	1,144,009	362,386					
1 star	1,144,009	362,386					
Green, 6 stars	1,099,588	335,680					
3 stars	1,118,539	354,631					
1 star	1,118,539	354,631					
Rockets, signal parachute, Mark I:							
Red caterpillar	1,368,530	413,854	255,000				5,000
White caterpillar	1,369,707	415,031	255,000				5,000
Green caterpillar	1,368,530	413,854	255,000				5,000
Red	386,506	159,326	106,024				109,159
Green	401,006	173,826	117,904		2,800		120,535
Yellow smoke	1,135,115	361,132	63,000		53,700		96,539
White illuminating	2,689,293	822,060	159,000		2,000		188,522
Flag	610,923	194,803	45,000				6,461
Amber			5,750				5,760
Rockets, signal, old style:							
Yellow smoke			36,100				36,100
Red			71,976		32,200		71,976
Green			60,096		57,175		60,096
Amber			35,697		31,000		36,062
Golden rain, Mark I			1,553				1,553
Cartridges, VB star, Mark I:							
White, 6 stars	1,638,572	483,832	95,000			[3] 110,000	101,120
3 stars	1,641,900	484,798	95,000				95,174
1 star	2,437,292	715,672	145,000				145,000
Red, 6 stars	673,452	203,692	40,150				40,150
3 stars	720,044	217,216	40,000				40,000
1 star	1,562,028	461,514	90,000				90,270
Green, 6 stars	673,452	203,692	40,000				40,000
3 stars	673,452	203,692	40,000				40,000
1 star	317,356	100,330	20,000				20,408
Cartridges, VB parachute, Mark I:							
White	3,573,320	1,043,520	200,000				205,117
Red	2,867,784	838,728	165,000				167,508
Green	2,867,784	838,728	165,000				165,210
White caterpillar	582,208	183,932					
Red caterpillar	488,264	148,048	30,000				30,000
Green caterpillar	488,264	148,048	30,000				30,234
Yellow smoke	405,064	123,888	20,000				0

[1] Impossible to determine quantity ordered and delivered until details of final settlement are received.
[2] Includes all types of rockets.
[3] Includes all types of VB cartridges.

Principal items in pyrotechnics—Continued.

Item.	Total require-ments.	Require-ments to Nov. 1, 1918.	Ordered in the U. S.	Ordered from abroad.	Floated from U. S.	Completed in U. S. to Nov. 11, 1918.	Total com-pleted in U. S.
Cartridges, Very parachute 25 mm.:							
White	1,969,246	695,192					
Red	1,509,594	464,755					
Green	1,509,594	464,755					
White caterpillar	3,481,434	1,037,110					
Red caterpillar	3,959,002	1,175,731					
Green caterpillar	3,959,002	1,175,731					
Yellow smoke	2,682,714	805,270					
Cartridges, Very star, 25 mm.:							
White, 1 star	6,781,497	1,955,272	100,000				0
Red, 1 star	1,884,345	573,802	100,000				0
Green, 1 star	1,884,345	573,802	100,000				0
Red, 6 stars	3,327,033	992,564					
3 stars	3,327,033	992,564					
Green, 6 stars	3,327,033	992,564					
3 stars	3,327,033	992,564					
Wing tip flares, Mark I:							
White	497,450	486,400	56,082		20,000	} 70,000	{ 47,882
Red	497,450	486,400	56,082		13,000		41,283
Airplane flare, Mark I	83,228	76,092	65,083			2,100	8,000
Position lights, Mark I (ground):							
White	2,883,123	892,251	305,000		10,798		150,002
Red	2,315,779	754,791	575,000		49,823	[1] 1,187,532	482,017
Green	2,315,779	754,791	380,000		19,856		275,417
Position lights, Mark II (hand), white	2,981,823	990,951	863,000		481,827		813,034
Smoke torch, Mark I	3,328,000	956,000	500,000			31,000	188,102
Rifle lights, Mark I, old style, white			320,000			55,000	55,000
Signal lights, Mark I, old style:							
White			29,000				0
Red			143,000				55,000
Green			143,000				55,000
Signal lights, Mark II, for Mark III pistols:							
White			1,000,000			[2] 2,661,008	994,360
Red			1,000,000				884,780
Green			1,000,000				720,348
Signal pistols:							
Mark III, 10-gauge			20,460				20,460
Mark I, 35-mm			29,669				1
Mark IV, 25-mm	194,680	97,016	166,719				25,066

[1] Includes all types of position lights.
[2] Includes all types of signal lights.

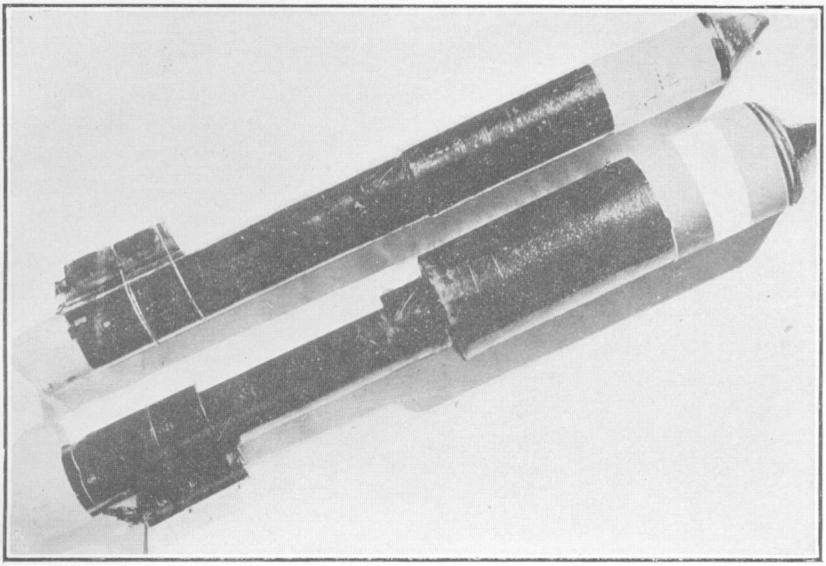
NOTE.—Columns relating to completions and flotations may be considered more or less as of armistice date, as cancellations became effective shortly thereafter.

COURSE OF DEVELOPMENT AND MANUFACTURE.

In the improvement of the rockets which were used by the Signal Corps, signal rockets Mark I and Mark II were developed and proved to possess 95 per cent efficiency in functioning and performance. This marked a distinct improvement over the rockets previously employed, and the new rockets also attained a height of 800 to 1,200 feet as compared with a height of 200 to 400 feet with the old rockets. The new rockets burned approximately one minute. Under Mark I were included the red and green rockets, and in addition a rocket known as the "golden rain" type, which had been substituted for the white rocket previously employed. This golden rain type in turn gave way to a rocket with an amber star.

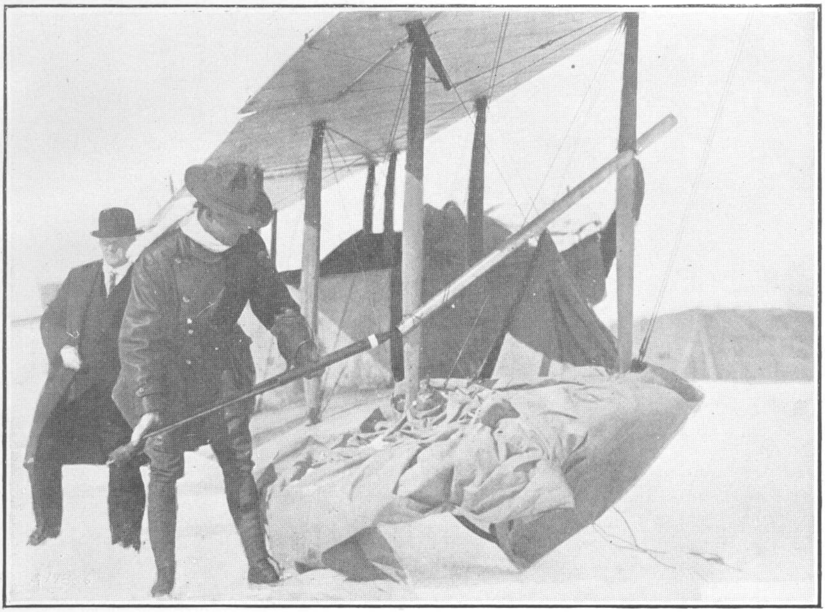
Later direction from France, however, led to the abandoning of this type in favor once more of a white rocket to be used for illuminating

PLATE 1a.



FLAG AND SIGNAL ROCKETS. TRENCH WARFARE SECTION, ORDNANCE DEPARTMENT, TOURS, FRANCE.

PLATE 2a.



TESTING INCENDIARY ROCKET AT MILITARY AVIATION FIELD, MINEOLA, L. I., NEW YORK, 1917.

as well as for signaling. Originally the day rocket using yellow smoke was designated "Signal Rocket Mark II."

The above references to efficiency and height attained, which are gathered from an Ordnance Department record, were doubtless based upon tests made under favorable conditions, for another Trench Warfare Division report confines the heights reached to 650 or 800 feet, and in conversation with a Signal Corps officer, who had been in France with the First Division, he called attention to the fact that 1,200 feet would be over twice as high as the Washington Monument; that he had seen rockets in service at the front, both of French make and of American make, that certainly none of them had reached the maximum height stated, and that his impression was that none of them had reached half that height. Regarding the matter of efficiency, he called attention to the catalytic action of certain chemicals employed in pyrotechnics, which caused deterioration. When questioned concerning the change from the golden rain type of rocket to the amber star, in the face of the general contention that it was more reliable to adhere to form rather than color in differentiation between signals, he stated that the change was probably made after it had been found that disintegration due to catalytic action within the rocket would cause a change in the form of the burst. Apart from yellow smoke, which was used mainly by headquarters, red, white, and green were the only colors employed.

In connection with rockets, position lights, and smoke torches, an ignition disk is provided with each piece, and on tearing off the protective band this ignition disk is made available to be rubbed by hand on a friction quick match, attached to the fuze, to cause the piece to function.

The VB signal cartridge was fired from a rifle grenade discharger attached to an infantry rifle. A .30 caliber blank cartridge was, however, used in the rifle, and this cartridge was taped onto each VB signal cartridge and detached at the time of use. The cartridges were marked for ready identification either by day or by night. At the beginning of our operations in France the organizations which used the VB signal cartridge encountered difficulty in its operation due to the fact that the blank rifle cartridge attached to the VB signal cartridge of French manufacture was the 8-millimeter cartridge, which did not fit the American rifle; hence it was necessary either to use French rifles or to extract the bullet from the American caliber .30 service cartridge before the signals could be used. The marking of the cartridges was in French and this caused trouble in identifying the different signals. Many misfires occurred due to the percussion cap in the French VB signal cartridge not being placed central with the firing pin, or placed too far away to be struck by the the firing pin inside of the signal cartridge, and in many cases when

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the cartridge did function, the parachute would fail to open. According to an Ordnance Engineering Division report received from overseas, there was a difference of opinion as to the desirable height of flight of this type of signal. On misty nights the signal would function above the mist and could not be seen, and in hilly terrain the signal would not function high enough to be seen on clear nights. To remedy this difficulty a blank cartridge with a heavy charge and a separate blank cartridge with a light charge could be developed. Contrary to reasoning with reference to the rockets, concerning the necessity for determining their source, it was specified that this VB signal must leave no trail of sparks, as such trail would aid the enemy in locating the position of the man who fired it. Experimental samples of the American manufactured VB cartridges, with blank cartridges attached, were received in France a few weeks before the armistice was signed, and in these the percussion cap of the signal cartridge was exploded by the pressure of the gases from the discharge of the rifle cartridge instead of by a firing pin as is used in the French type.

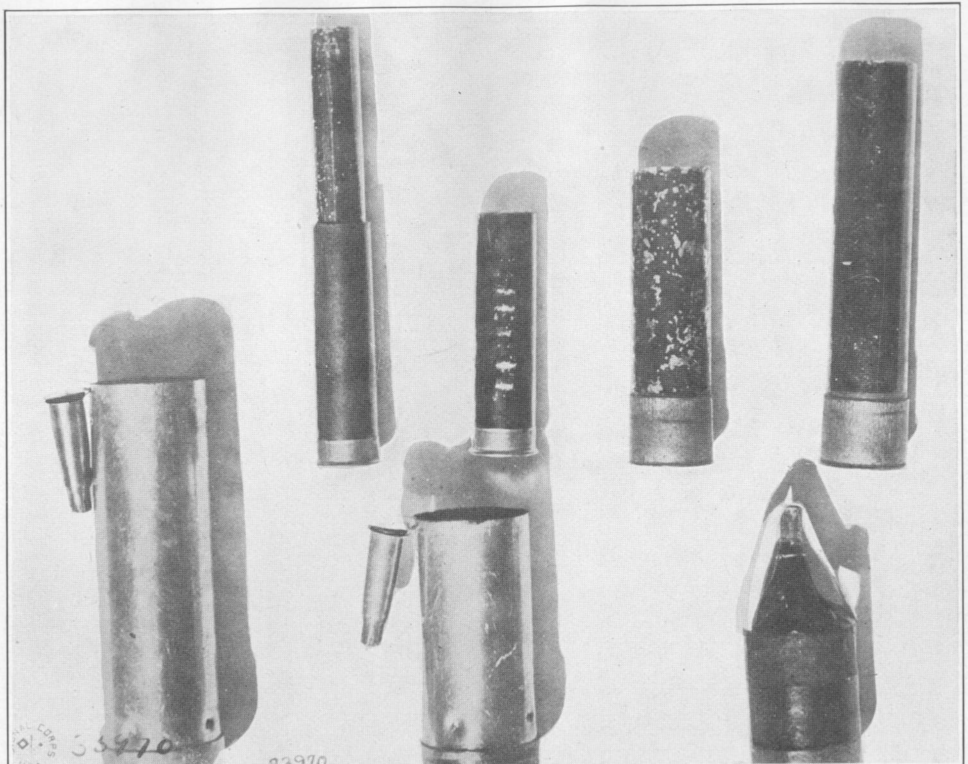
Signal light Mark I was designed to be used in conjunction with the VB discharger and the Army rifle for signaling purposes by the Infantry. The light functioned satisfactorily but the American Expeditionary Forces would not accept the device, as there was a trail of sparks from the signal when it was fired. As these signals were used only at night this would enable the enemy to locate the man firing the signal. The VB discharger Mark I, developed from the French design, was therefore adopted instead of the rifle light, as the VB cartridge signal did not leave a trail of fire.

The rifle light Mark I is a development from the Frankford Arsenal rifle grenade, illuminating, and was designed to be thrown from a VB rifle discharger. It contains an illuminating pellet, suspended by a parachute and burning 20 seconds with from 40,000 to 60,000 candlepower. The parachute was of such size as to suspend the illuminant at practically the point of burst until consumed and the cost of the new cartridge was less than one-fourth that of the Frankford Arsenal type.

This is a matter of nomenclature of a development of about November, 1917, on the same work order with signal light Mark I. The specimen retained of the signal light was produced by the Nixon Fulgent Products Co. and that of the rifle light by the Unexcelled Manufacturing Co.

CARTRIDGES FOR 25-MILLIMETER VERY PISTOL (PYROTECHNICS).

These cartridges were used in conjunction with the 25-mm. Very pistol Mark IV for signaling purposes by troops. Sixteen types of these cartridges were authorized, including signals both with and with-



TYPES OF SIGNAL CARTRIDGES 25 MM. AND 35 MM.

In the upper type the propelling charge is a part of the cartridge. In the lower type the propelling charge is separately contained. In the lower right of the photo is a signal light. Trench Warfare Section, Ordnance Department, Tours, France.

UNCLASSIFIED

out parachute. Orders were placed in the United States for 300,000 of the cartridges, but at such a late date that none were produced. The cartridge case of the 25-mm. cartridge not being of the standard American size none of the shotgun cartridge manufacturers desired to produce the paper-cartridge case. Contracts were therefore awarded for metal cartridge cases and apparently these were entirely satisfactory. It was in cablegram 1005–6A of April 27, 1918, that we were advised by the American Expeditionary Forces that the No. 10 gauge size of signal cartridge appeared to be too small for signal work, and it was their belief that it would be necessary for us to develop the 25-mm. or 1-inch size.

SIGNAL LIGHT MARK II (VERY).

In connection with the Very pistol cartridge, which had been issued by the Navy to the Signal Corps, the composition was not considered stable by the Army Ordnance Department nor was the degree of visibility considered satisfactory and hence new specifications were provided by the Ordnance Department. This new cartridge was known as "Signal Light Mark II." This signal was used by the Navy before the present war and adopted by the Army. Total weight approximately 1 ounce. Used in conjunction with Very signal pistol model Mark III by the Infantry. Contracts were awarded and large quantities made but the signals were abandoned on instructions from the American Expeditionary Forces, as it was decided that our signal cartridges should be the same size as the French so that signals could be interchangeable between troops.

CARTRIDGE FOR 35-MILLIMETER SIGNAL PISTOL (PYROTECHNICS).

This cartridge was used for signaling purposes in aviation in conjunction with the 35-millimeter signal pistol (aviation). Twenty different types of 35-millimeter cartridges were authorized in the pyrotechnics program but no contracts were awarded, as before the production was started in the United States the caliber was changed to 25 millimeters. In general it may be said that the cartridges for use in the same pistol, while of the same caliber, were not all of the same length; in fact, the ends of some of the cartridges would extend far beyond the muzzle of the pistol. The difference in length was due to the quantity of pyrotechnic material which was called for by the type of signal for which the cartridge was used; that is, the length of the caterpillar or the number of stars. For aviation work it was not necessary to have any considerable amount of propelling charge in the cartridge, as the altitude was provided for by the plane being in the air, and it was only necessary to propel the signal a

short distance clear of the plane. For Very pistol cartridges to be used from the ground, however, a stronger propelling charge was necessary in order to provide for the functioning of the signal at the proper altitude.

In a letter dated September 19, 1919, from the Engineering Division of the American Expeditionary Forces regarding these cartridges, the point is brought out that at that time the French were using a signal burning first in one color and then changing to another color and that the adoption of this changing type was not known to the American Expeditionary Forces until it was actually in service. The thought expressed by the American Expeditionary Forces was that there was a chance that one of the colors might not function and that thus the proper signal would not appear and a serious misunderstanding might result. This brings to mind the reference to the uncertainty in the operation of some of the military pyrotechnics through catalytic action, and possibly through dampness, as referred to in a previous part of this chapter.

VERY SIGNAL PISTOL, MARK III.

This pistol was used by the Navy prior to the present war, and was adopted by the Army. It was used by the Infantry in conjunction with the signal light Mark II (Very). A contract was awarded to the Remington Arms Co., Bridgeport, Conn., for the manufacture of a quantity of these pistols but on receipt of word from the American Expeditionary Forces that the signal cartridges should be of the same size as the French, the contract for these pistols was canceled, and the 25-millimeter Very pistol, Mark IV, was adopted to supersede it. Some of the No. 10 gauge Mark III pistols had been shipped abroad but were returned to this country and were used for training purposes.

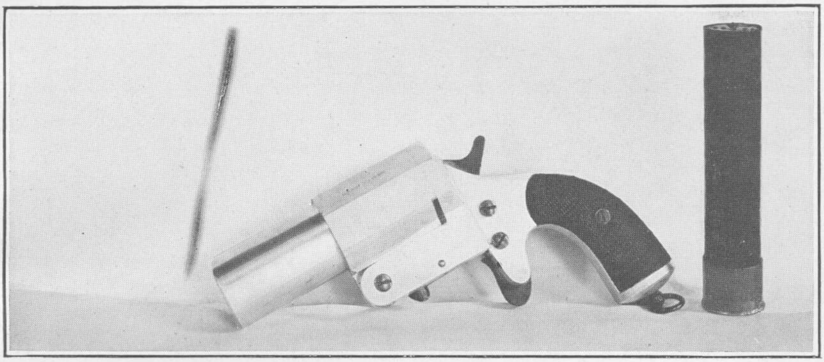
25-MILLIMETER VERY PISTOL, MARK IV.

This pistol was used by our Infantry for signaling purposes. There were no particular difficulties encountered in production and the number ordered and produced are indicated in the table dealing with production.

25-MILLIMETER VERY PISTOL, FRENCH MODEL 1917.

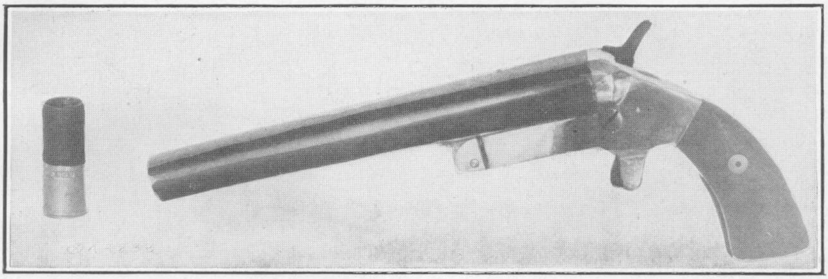
This pistol was used for signal work and is the latest type designed by the French. In Weekly Letter of September 7, 1918, from the Ordnance Department at Washington to the American Expeditionary Forces, attention was called to a pamphlet which had been received from France regarding this model and particularly to the radically different grip, the longer barrel of steel instead of brass, and other minor changes as compared with the 25-millimeter Very pistol, Mark IV, then in production. The thought was advanced that possibly

PLATE 4a.



VERY SIGNAL PISTOL, WITH CARTRIDGE. FOR USE FROM AIRPLANE FOR COLORED FLASH SIGNALS, ETC.

PLATE 5a.



VERY PISTOL AND CARTRIDGE.

the powerful recoil of the pistol made necessary a different construction and a different grip and that a greater range was desired, thus accounting for the length of the barrel. It was requested that a definite statement be made whether or not it was desired to put the new French model into production, and reply of October 3 stated that the new French model had not been tested and that they were not in a position to state that it was superior to the one which was already in production in the United States. They recommended, however, that tests be made here, and if the new model proved superior to a marked degree that it be put into production as soon as existing contracts on the older design were completed. In both of these letters the new design was referred to as that of 1918. Tests were made and the opinion was expressed that it was not as satisfactory a pistol as the Mark IV, as the locking mechanism worked too hard and the trigger-pull was too great. No production was started.

35-MILLIMETER SIGNAL PISTOL, MARK I (AVIATION).

This pistol was used by aviators to fire signal cartridges. Contracts for 29,669 were awarded to the Dohler Die Casting Co., Brooklyn, N. Y., the Hammond Typewriter Co., New York City, and the Parker Bros. Gun Co., Meriden, Conn. One pistol was produced. Prior to the introduction of this pistol, we had no pistol for aviation work and adopted the French design. The American design was satisfactory except for the firing pin and firing-pin spring. In connection with this a different type of hammer is desirable to eliminate the necessity for placing the hammer at half cock in order to load the pistol.

35-MILLIMETER SIGNAL PISTOL, MARK II (AVIATION).

This pistol is the same as the 35-millimeter signal pistol, Mark I (aviation), except that the French design is followed more closely in detail. It was proposed to use the above title to identify the new drawings which would be used in the manufacture of sand-cast aluminum parts instead of die cast, as had been used in the 35-millimeter signal pistol, Mark I. The die-cast pistol proved successful, so this project was abandoned.

35-MILLIMETER SIGNAL PISTOL (BRASS).

Five sample pistols of French design were received from abroad. This pistol was designed by the French to take the place of the 35-millimeter signal pistol, Mark I, but information was received to the effect that no improvement was apparent, and an experimental order placed in the United States for the manufacture of 20 of the brass pistols was canceled.

35-MILLIMETER SIGNAL PISTOL, MARK III (AVIATION).

This project was authorized under this nomenclature for the copy of a new French model, but word being received from abroad that certain defects in the 35-millimeter signal pistol, Mark I, had been eliminated, it was the opinion that the Mark I pistol was a better design than the Mark III, and hence no further action was taken in this project.

POSITION LIGHT, MARK I, WHITE, RED, AND GREEN (GROUND).

Steps were taken to develop a ground position light, but during the experimental stage a modified form of the British ground flare was adopted. The device, which was later independently perfected by the Ordnance Department, is known as "Position light, Mark I, ground." There are three types—white, red, and green. Each type burns about a minute. The white is of about 5,000 candle power; the red, about 1,400, and the green, about 1,200. These are regarded as superior to any other known pyrotechnic devices of the kind.

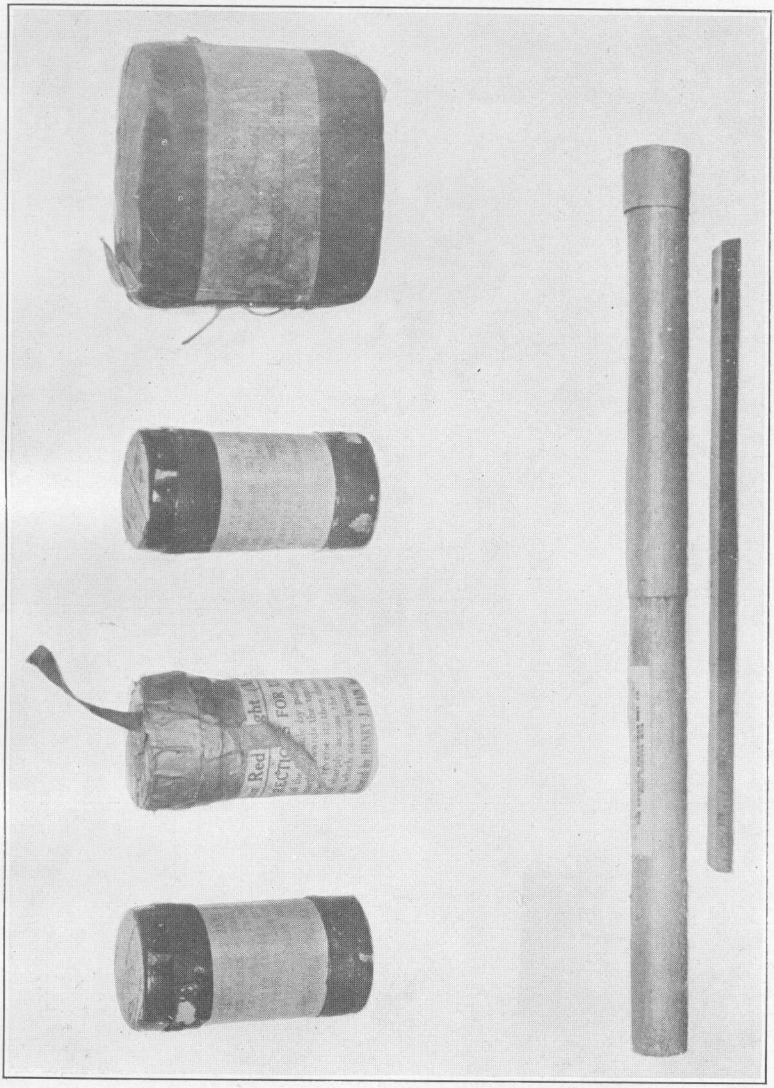
This is a development of the position light of the Engineering Corps and of the British ground flare. It weighs from 4¼ to 5¼ ounces, varying with the color. Its use is in conjunction with troop movements. It is provided with a friction igniter and when ignited is placed or thrown upon the ground. As in the case of the hand position lights, they were also used at times by airplane squadrons for marking the landing field at night.

Smoke torch, type "S," adopted by our forces was used both as a signal and for producing a smoke screen. It is of British manufacture and was not manufactured in the United States. It burns for approximately five minutes, giving a dense yellow smoke. The smoke composition is packed in a metal case approximately 3¾ inches in diameter, and about 6 inches long, and is ignited by a friction striker. The size and weight were carefully considered in the design of this torch, due to the fact that it was necessary for the soldier to carry it. Samples of two types were sent to the United States and both were considered satisfactory by our troops.

SMOKE TORCH, MARK I.

Of the types of pyrotechnics, which were more or less developed in our service at the outbreak of the war, the American smoke torch was arranged like the British type, which had been followed, to burn from 2½ to 3 minutes. It gave out, however, a considerably larger volume of smoke, as compared with the samples received here, and, later, on cable advice from the American Expeditionary Forces, the burning time was increased to 4 minutes, and the design and chemical

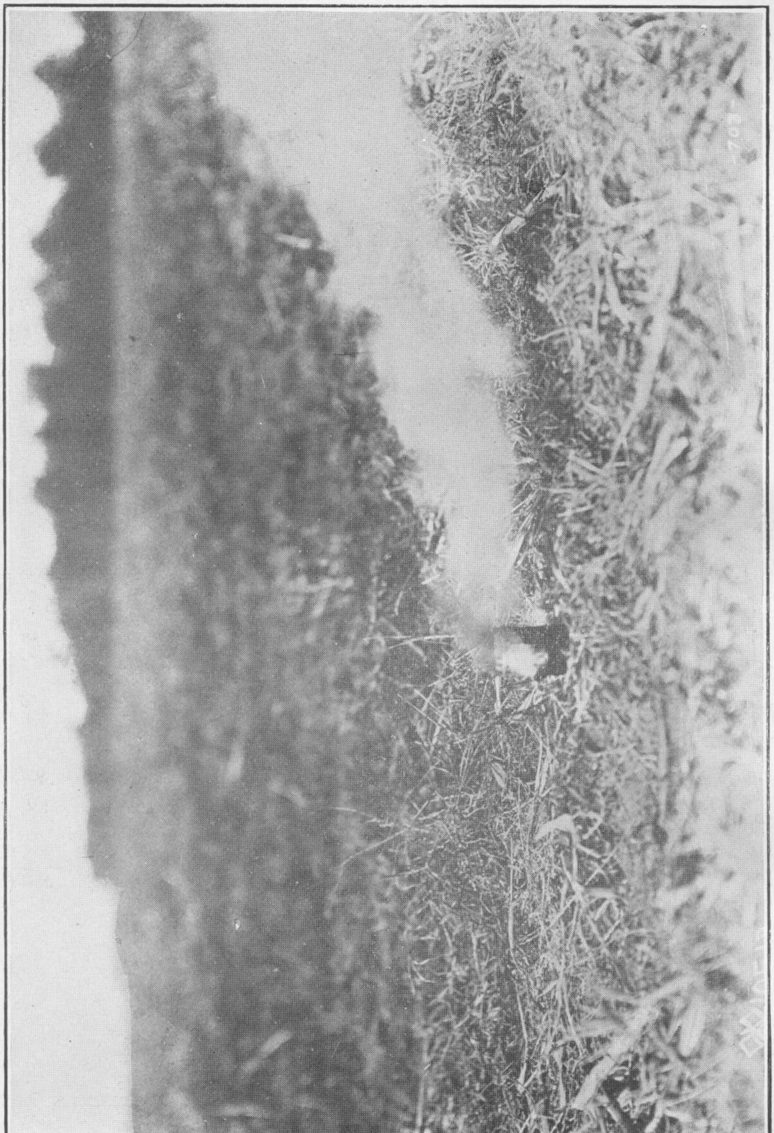
PLATE 6a.



TYPES OF ORDNANCE SIGNAL LIGHTS. POSITION LIGHT MARK I (ABOVE). POSITION LIGHT MARK II.

UNCLASSIFIED

PLATE 7a.



SMOKE TORCH.

UNCLASSIFIED

formula adopted resulted in smoke torch, Mark I. The smoke torch, Mark I was manufactured in the United States and was in quantity production when the armistice was signed.

Holt wing tip flares, which were used by our air squadron, were of British manufacture. The flare is ignited by means of an electric squib imbedded in the upper end of the flare and connected to a switch in the fuselage of the plane. Two types of these flares were used; one giving a red mist-penetrating tinge, and the other a white light. Much difficulty was encountered in the use of these flares through the failure of the electric squib to function. Instead of using two to a plane to insure illumination for night landing, the aviators were using six and eight to a plane.

The American adaption, known as the *wing tip flare, Mark I*, was also made with the white light and with the red tinge, and while laboratory results of 22,000 to 25,000 candlepower were obtained, difficulty encountered in connection with the quality of the chemicals obtainable at the time resulted in production requirements being reduced to a minimum of 12,000 candlepower for the white flare and a minimum of 6,000 candlepower for the red tinge flare. The burning time was 1 minute.

Airplane flare, Mark I, modeled after the Michelin illuminating bomb, was designed for use in aviation work to illuminate the country which the aviator desired to bomb and also occasionally for landing purposes. It consists of a thin sheet-metal cylinder, about 4 feet long and 4 inches in diameter, provided with guiding fins at the tail of the cylinder a small metal revolving vane at the nose, and two projecting buttons for providing means for attachment to a releasing device for providing means for attachment to a releasing device located underneath the wings of the plane. The cylinder contains an igniting device, an expelling charge, an inner case containing the illuminating compound, and a silk parachute connected by cords to the inner case. The mounting of the vaned wheel consists of a brass stud or shaft passing through the nose carrying on its inner end the ignition striker. This stud or shaft, instead of having a smooth bearing through the nose piece, is threaded for a portion of its length, and is likewise provided with a flat surface, and a cotter pin hole at that part of the shaft which is exterior to the nose piece.

During shipment and handling a cotter pin passing through the hole in the shaft prevents the firing pin striking the ignition surface. On being mounted on the plane the cotter pin is removed and the flare is attached by means of the attachment buttons provided to a releasing device on the lower side of the wing, and, in so attaching, the flat surface on the shaft of the vaned wheel is inserted in a clip which prevents the shaft from turning. At such time as the aviator desires to release the flare, he operates from the fuselage the mechanical connection to

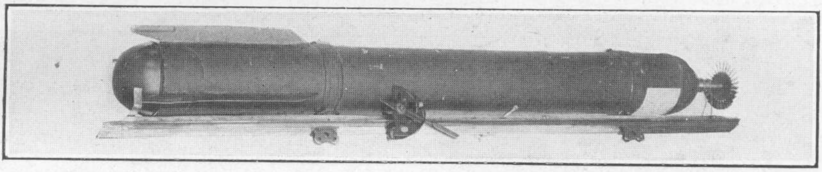
the releasing device, and the cylinder then drops free from the plane and the vaned wheel commences to turn as a result of the action of the impinging of the air against it, as would be the case with a windmill or pinwheel. In so revolving, the shaft advances on the thread in its bearing until its roughened inner end is forced into friction contact with the quick match which ignites the expulsion charge. Ordinarily this occurs when the flare casing has dropped about 200 or 300 feet below the plane. On the ignition of the expulsion charge, the inner case, together with the parachute, is expelled from the outer case at the guiding vane end of the cylinder and the illuminating charge in the inner case is ignited. The parachute opens and the burning illuminant is thus suspended and permitted to slowly descend toward the earth.

The above is a description of the manner in which the flare is designed to function. Its total weight is about 36 pounds. It is the best flare of this character that has thus far been developed, but it is not an entirely satisfactory device. Its successful functioning is dependent upon a train of action and the failure of any part to function affects the successful operation. It is felt that the entire firing mechanism should be changed to insure more positive action of the firing pin. A clockwork time mechanism has been developed and will probably receive further consideration. Some difficulty has been experienced in the ignition of the illuminant due to the first fire breaking away from the illuminant when the parachute has opened. It is felt that some parachute failures are bound to occur, due either to the parachute not opening properly or to the breaking of the suspension cords. In the present device no means is provided for an adjustable fuze.

The airplane flare of American design was designed to burn about 7 minutes with from 225,000 to 350,000 candlepower, as compared with a burning time of 6 minutes and 55 seconds and a candlepower of 190,000 in the French Michelin type.

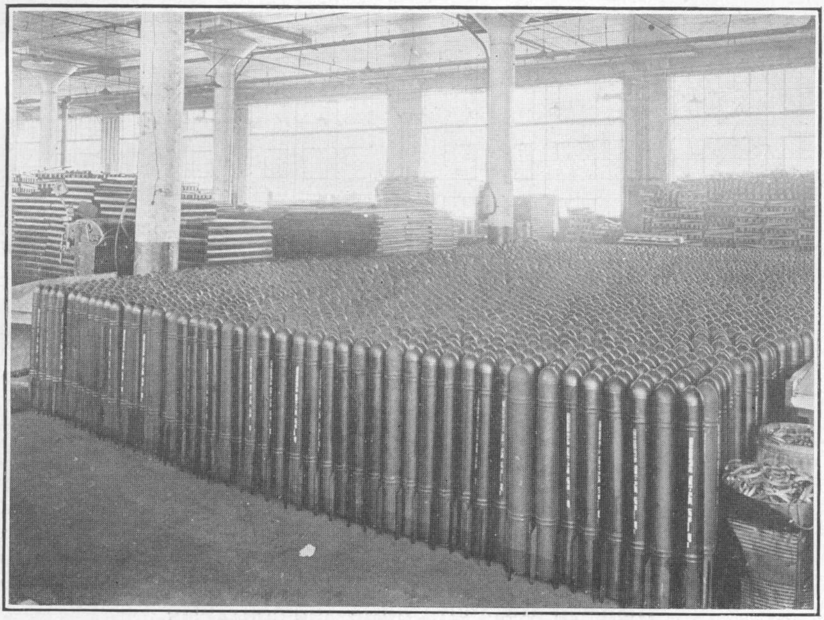
The airplane flare Mark II is an adaptation of the French Bourges illuminating flare and is used in conjunction with night observation from airplanes. It was designed to be thrown from the airplane by the pilot or the observer and is employed in an emergency and as an auxiliary to airplane flare Mark I. The French flare is cylindrical in shape, with a length of 20 inches and a diameter of 2¾ inches. The illuminant is suspended by a cloth parachute which is from 3 to 4 feet in diameter. A time fuze is provided which can be set to the number of seconds desired by the aviator. In operation the flare is dropped from the airplane by the aviator or observer and is caused to function by pulling a small string attached to the firing mechanism. The experimental work was carried on by the pyrotechnic laboratory of the Ordnance Department, and it did not go beyond the experimental

PLATE 8a.



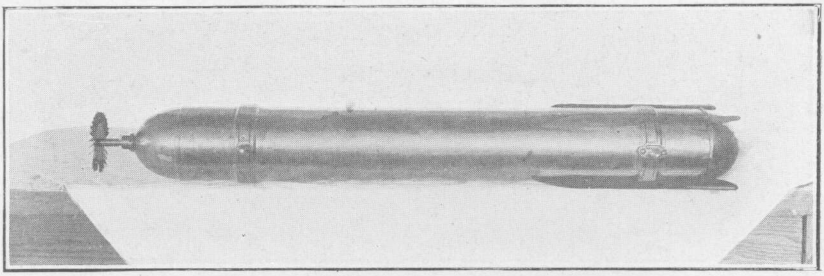
AIRPLANE FLARE MARK I.

PLATE 9a.



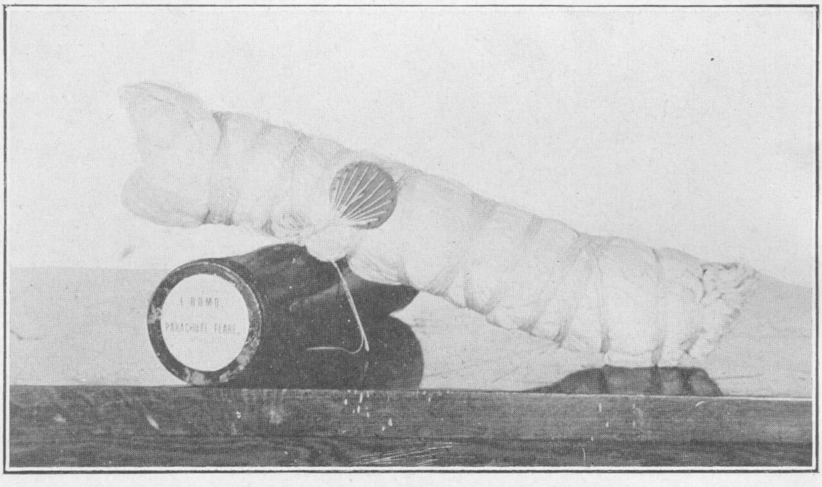
ONE DAY'S OUTPUT OF FLARE BOMBS FOR THE SIGNAL CORPS.

PLATE 10a.



MICHELIN PARACHUTE FLARE..

PLATE 11a.



MICHELIN PARACHUTE, BOMB, AND CONTAINER.

stage. Apart from the tests for candlepower, the experimental work was confined to different forms of firing mechanisms, along the lines of standard ignition, the grenade type of ignition, and clockwork and friction types of ignition. The illuminating composition made up at the pyrotechnic laboratory had a burning time of 3 minutes and developed a candlepower of 110,000.

In the French manufacture this Bourges flare is considerably smaller than the Michelin flare from which with wing tip flare, Mark I, was adapted, and has a time fuze which arms it to function much nearer the ground and it is in much greater favor with the aviators than the Michelin flare. A dozen Bourges flares can be carried in the fuselage of the plane while only 2 or 3 Michelin flares can be carried, and these must be suspended from the Michelin releasing mechanism underneath the wings or the fuselage. The Bourges flare is fired by the aviator jerking a cord at the instant he throws the flare clear of the plane. This cord releases the firing pin which is under compression. The firing pin strikes a cap which ignites a time fuze. The objectionable feature of this flare is that the fuze is always armed and recommendation was made that safer firing mechanism be developed. It was suggested that the Bourges flare with a yellow or mist-penetrating light be developed, as this would greatly aid night flying in the zone in which the squadron was operating. The timing arrangement of the fuze should have a greater range. Drawings, specifications, and samples were sent to the United States with a request that they be put into production immediately.

SMOKE MESSAGE TUBE (AIRPLANE).

The message cartridge for the 35-millimeter pistol (aviation) was to some extent used for sending information such as reconnaissance reports, maps, etc., from the airplane to the land force. This cartridge did not have sufficient capacity to meet the requirements of our air squadron. The aviators improvised a type of message tube consisting of a tin can with a cloth streamer, and this worked out satisfactorily with the exception that it did not have a smoke tracer. The idea of the smoke tracer is to aid the watcher on the ground in locating the message after it has reached the ground, and its smoke must be of such color that it can be distinguished from the smoke of bombs or shell. To attract attention before dropping the message, the aviator would blow a whistle or a horn, or in some cases, would fire a few shots from his machine gun in order to attract attention to the message which was about to be released. Tentative drawings were prepared by the Engineering Division of the American Expeditionary Forces of a smoke message tube having a message-carrying capacity 8 inches long by 2 inches in diameter and providing for the ignition of the smoke composition which was located in a compartment in one

end of the tube by means of a Mark II offensive hand grenade bouchon without the detonator.

Work was also being carried on in the United States in the development of a smoke message tube when the armistice was signed.

OFFENSIVE GRENADE FLARE.

The object of this grenade was to replace the Very signals used in aviation, it being much simpler and easier to throw one of these grenades from the plane than to load and fire a pistol. It was developed at the Ordnance pyrotechnic laboratory and the tests conducted with experimental grenades indicated that they could be manufactured to function equally as well as the Very cartridges. The unsatisfactory feature lies in the fact that the star may be blown back onto the plane, as the direction in which the star is expelled can not be controlled. The matter was in an experimental stage at the time of the armistice.

ILLUMINATING BOMB AND GUN, MARK I.

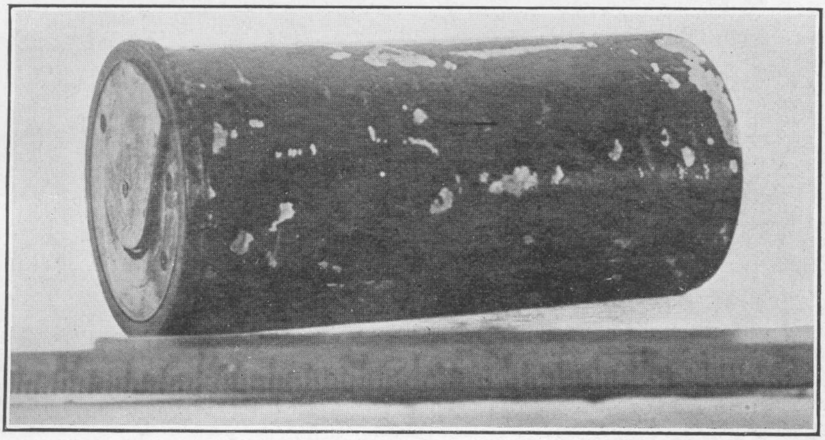
This was an experimental project to provide an illuminating shell of greater range than the rocket. The shell was loaded with a single illuminating star and a 36-inch parachute. The illuminating composition was designed to burn about 20 seconds, giving a candlepower of 60,000 or more. The shell was to burst about 350 feet from the ground and the fuze to give a maximum range of 1,500 feet. The project was not carried beyond the experimental stage, and it was decided to use the Stokes' mortar and modify the Stokes' shell for illuminating purposes.

DROPPING DEVICE FOR INCENDIARY DARTS.

The purpose of this device was to provide a means for the carrying of incendiary darts by airplanes and the dropping of them upon objects which could be set on fire. The project was in the experimental stage at the signing of the armistice. The device was designed to be attached to the standard bomb-carrying device of D. H.-4 airplanes, using the standard release mechanism. A safety device was incorporated in the loading bucket and precluded the possibility of the darts becoming ignited while in the dropping device. The device is pivoted on trunnions at one end, and when released swings about these trunnions in a vertical downward arc, which is retarded slightly at the point when the dropping bucket is pointing directly downward, thus allowing the darts to be spilled. The retardation is then relieved and the remaining momentum of the device, together with the wind pressure due to the movement of the airplane, completes the movement and the empty bucket swings up under the wing of the airplane, where it is caught and held by suitable latches. The value of the device has not yet been demonstrated.

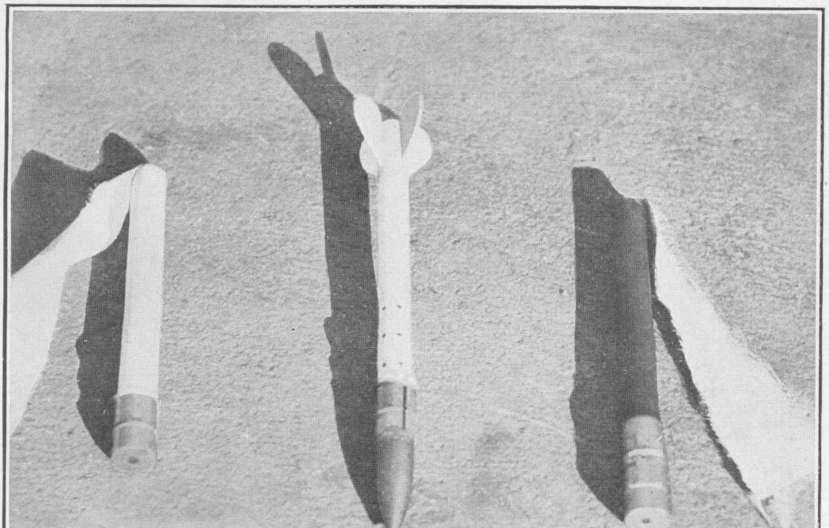
UNCLASSIFIED

PLATE 12a.



ILLUMINATING BOMB, MARK I.

PLATE 13a.



INCENDIARY DROP DARTS, AIRPLANE TYPE.

UNCLASSIFIED

The darts to be carried by this device were the incendiary darts, Mark I; the bucket being loaded with 61 darts. The assembled weight loaded was approximately 60 pounds, of which weight 25 pounds represented the weight of the darts.

The incendiary dart, Mark I, was between 11 and 12 inches in length and about 1 inch in diameter. It consisted of a tube containing an incendiary mixture, a nose with striker and cap to ignite the mixture on impact with the ground, and a stabilizer to insure the dart traveling nose downward when released from a plane. In the experiments a cloth stabilizer was at first employed and later a vaned paper stabilizer was used. The basic idea was to provide a dart which on striking the ground would send a radial shower of flame several feet high for the purpose of igniting grain fields or other readily ignitable objectives.

The Mark I incendiary dart was constructed to permit the carrying of large quantities of darts in an airplane, it being considered that as many as 1,000 darts might be carried at one time in a large plane and that it would be possible to scatter the incendiary units over a considerable area. A quantity of darts were sent to France but they were condemned there as not being suitable for the purpose. Those are doubtless fully reported upon by the Chemical Warfare Service.

At the time that the United States was ready to initiate its manufacturing program, only three or four plants were available for quantity production; one of the manufacturing companies having just been organized.

The tabulation immediately preceding will in general indicate the quantity orders placed, and for the presentation of contract details the "History of Production of Pyrotechnics," prepared by the Trench Warfare Division of the Army Ordnance Department and submitted on January 3, 1919, is reproduced.

CHAPTER II.

HISTORY OF THE PRODUCTION OF PYROTECHNICS.

SIGNAL ROCKETS.

JANUARY 3, 1919.

The first contract was let to Unexcelled Manufacturing Co., New York, on December 1, 1917. Quantity production started in January. On May 13, 1918, the Engineering Division changed specifications to conform to French types. This radical change made it necessary for manufacturers to alter their plans considerably. Production of old style signal rockets was as follows:

Article and firm.	Contract No.	Date.	Contracted for.	Completed.
Mark II. Yellow smoke:				
Unexcelled Manufacturing Co	G1121-424TW	Nov. 30, 1917	20,000	20,000
Henry J. Paine	G1191-440TW	Nov. 27, 1917	10,000	10,000
Unexcelled Manufacturing Co	P3274-1128TW	Feb. 22, 1918	6,000	6,000
Henry J. Paine	P3574-1236TW	Mar. 1, 1918	100	100
Total			36,100	36,100
Mark I. Golden rain:				
Unexcelled Manufacturing Co	G1121-424TW	Nov. 30, 1917	1,188	1,188
Henry J. Paine	G1193-442TW	Nov. 27, 1918	365	365
Total			1,553	1,553
Mark I. Amber:				
Unexcelled Manufacturing Co	G1121-424TW	Nov. 30, 1917	8,812	8,812
Henry J. Paine	G1193-442TW	Nov. 27, 1917	9,635	10,000
Unexcelled Manufacturing Co	P3273-1127TW	Feb. 22, 1918	17,250	17,250
Total			35,697	36,062
Mark I. Red:				
Unexcelled Manufacturing Co	G1121-424TW	Nov. 30, 1917	20,000	20,000
National Fireworks Co	G1190-439TW	Nov. 27, 1917	7,500	7,500
Henry J. Paine	G1193-442TW	Nov. 27, 1917	22,500	22,500
Unexcelled Manufacturing Co	P3275-1127TW	Feb. 22, 1918	4,976	4,976
Total			54,976	54,976
Grand total			128,326	128,691

The changes in design of signal rockets which started on May 13, 1918, were put into effect at the different manufactories as rapidly as possible. Samples were submitted by the manufacturers to meet the requirements. Quantity production on the new types started the latter part of July. Production accepted by Government inspectors up to December 8, 1918, was as follows:

Article and firm.	Cuntract No.	Date.	Contracted for.	Completed.
Mark I. Red:				
Unexcelled Manufacturing Co	P3273–1127TW	Feb. 22, 1918	28, 024	16, 000
National Fireworks Manufacturing Co.	P14553–2441TW	Sept. 4, 1918	50, 000	11, 000
Unexcelled Manufacturing Co	P15167–2504TW	Sept. 19, 1918	25, 000	17, 000
Henry J. Paine	P15484–2538TW	Sept. 26, 1918	20, 000	17, 000
Total			123, 024	61, 000
Mark I. Green:				
Unexcelled Manufacturing Co	P3273–1127TW	Feb. 22, 1918	25, 904	25, 904
National Fireworks Manufacturing Co.	P14553–2441TW	Sept. 4, 1918	50, 000	8, 000
Unexcelled Manufacturing Co	P15167–2504TW	Sept. 19, 1918	25, 000	25, 000
Henry J. Paine	P15484–2538TW	Sept. 26, 1918	20, 000	18, 000
Total			120, 904	76, 904
Mark I. Amber:				
Unexcelled Manufacturing Co	P3273–1127TW	Feb. 22, 1918	5, 750	5, 750
Mark I. Yellow smoke:				
Unexcelled Manufacturing Co	P3274–1128TW	Feb. 22, 1918	24, 000	24, 000
Henry J. Paine	P3574–1236TW	Mar. 1, 1918	39, 900	39, 900
Total			63, 900	63, 900
Mark I. White:				
Unexcelled Manufacturing Co	P3273–1127TW	Feb. 22, 1918	29, 000	29, 000
Henry J. Paine	P3556–1233TW	Mar. 4, 1918	35, 000	35, 000
National Fireworks Manufacturing Co.	P14553–2441TW	Sept. 4, 1918	50, 000	1, 000
Unexcelled Manufacturing Co	P15167–2504TW	Sept. 19, 1918	25, 000	25, 000
Henry J. Paine	P15484–2538TW	Sept. 26, 1918	20, 000	20, 000
Total			159, 000	110, 000
Grand total			472, 578	317, 562

In order to aid production the Government started to furnish paper parachutes to manufacturers in September, 1918. Some of these were imported from Japan and some sewed in this country. The contracts let with the production to December 12, 1918, were as follows:

Article and firm.	Contract No.	Date.	Contracted for.	Completed.
28-inch domestic sewed: Japan Paper Co	P14841–2476TW	Sept. 12, 1918	31, 700	31, 700
28-inch imported: Japan Paper Co	P14841–2476TW	do	27, 000	27, 000
28-inch domestic sewed: Japan Paper Co	P15282–2512TW	Sept. 21, 1918	95, 000	95, 000
28-inch imported: Japan Paper Co	P15282–2512TW	do	25, 000	23, 000
28-inch domestic sewed: Japan Paper Co	P15405–2532TW	Sept. 24, 1918	1, 000, 000	230, 000
Do	P15551–2548TW	Sept. 25, 1918	28, 700	28, 700
Total			1, 205, 400	435, 400
32-inch imported: Japan Paper Co	P15282–2512TW	Sept. 21, 1918	90, 000	90, 000
32-inch domestic sewed: Japan Paper Co	P16310–2657TW	Oct. 9, 1918	630, 000	170, 000
32-inch imported: Japan Paper Co	P16418–2671TW	Oct. 15, 1918	1, 000, 000	90, 000
32-inch domestic sewed: Japan Paper Co	P17797–2815TW	Nov. 6, 1918	400, 000	77, 700
Total			2, 120, 000	427, 700
34-inch imported: Lewis Nixon	P15402–2529TW	Sept. 24, 1918	103, 000	103, 000
36-inch imported: Japan Paper Co	P16961–2716TW	Oct. 22, 1918	210, 000	187, 500
Flag imported: Japan Paper Co	P15791–2472TW	Sept. 11, 1918	5, 000	5, 000
Do	P16314–2661TW	Oct. 5, 1918	40, 000	....
Total			45, 000	5, 000
Grand total			3, 683, 400	1, 158, 600

POSITION LIGHTS.

The first contract for position lights was for the hand type, Mark II, let to Henry J. Paine on December 19, 1917. The first produc-

tion passing Government inspection was the first part of February, 1918. Contracts for the hand type, Mark I, were first let the early part of March, 1918, and by the middle of May quantity production was passed Government inspection. It was necessary for several changes in specifications to be made. The most radical of which were made June 14, 1918, covering formulæ, time of burning, and candlepower. Since that time, the manufacturers adapted their production to the new specifications as rapidly as their samples could be made to pass the necessary tests. Considerable trouble was encountered, but by August 1 the Mark II hand-type position lights had reached a steady maximum quantity production. The Unexcelled Manufacturing Co. were not able to reach quantity production on the ground type Mark I until September, 1918. In the meantime, however, the Nixon Fulgents Product Co. were able to turn out their contract complete by July 20, 1918. The contracts let and production accepted by Government inspection up to December 12, 1918, are as follows:

Article and firm.	Contract No.	Date.	Contracted for.	Completed.
Mark II. Hand, white:				
Henry J. Paine	G1192-441TW	Nov. 27, 1917	50,000	50,000
Unexcelled Manufacturing Co	G1274-472TW	Dec. 8, 1917	50,000	50,000
Do	P3280-1134TW	Feb. 22, 1918	485,000	485,032
Henry J. Paine	P15487-2541TW	Sept. 24, 1918	27,000	27,000
Unexcelled Manufacturing Co	P15554-2549TW	Sept. 27, 1918	30,000	30,000
Essex Specialty Co	P16250-2651TW	Oct. 10, 1918	50,000	....
Henry J. Paine	P3557-1234TW	Mar. 4, 1918	165,000	165,000
Total			857,000	807,032
Mark I. Ground, white:				
Unexcelled Manufacturing Co	P3275-1128TW	Feb. 22, 1918	132,000	132,002
Lewis Nixon	P3856-1291TW	Mar. 8, 1918	18,000	18,000
Unexcelled Manufacturing Co	P15792-2569TW	Sept. 26, 1918	50,000	....
Essex Specialty Co	P16250-2651TW	Oct. 10, 1918	100,000	....
Total			300,000	150,002
Mark I. Ground, red:				
Unexcelled Manufacturing Co	P3275-1129TW	Feb. 22, 1918	330,000	330,017
Lewis Nixon	P3656-1291TW	Mar. 8, 1918	45,000	45,000
Do	P13417-2345TW	Aug. 12, 1918	45,000	45,000
Unexcelled Manufacturing Co	P15792-2569TW	Sept. 26, 1918	50,000	50,000
Essex Specialty Co	P16250-2651TW	Oct. 10, 1918	100,000	12,000
Total			570,000	482,017
Mark I. Ground, green:				
Unexcelled Manufacturing Co	P3275-1129TW	Feb. 22, 1918	198,000	74,017
Lewis Nixon	P3656-1291TW	Mar. 8, 1918	27,000	27,000
Unexcelled Manufacturing Co	P15792-2569TW	Sept. 26, 1918	50,000	....
Essex Specialty Co	P16250-2651TW	Oct. 10, 1918	100,000	....
Total			375,000	101,017
Grand total			12,102,000	1,540,068

RIFLE LIGHTS MARK I, SIGNAL LIGHTS MARK I, AND VB CARTRIDGES.

Production was well under way on contract for 2,000,000 rifle lights, Mark I, and signal lights, Mark I, when on June 13, 1918, the Engineering Division notified us that these articles would have to be

completely changed to the French types. Production was stopped. The French types are known as VB star and parachute cartridges, of which there are about 20 types. Quantity production on these types started about October 15, 1918. The contracts let and production accepted by Government inspection up to December 12, 1918, are as follows:

Article and firm.	Contract No.	Date.	Contracted for.	Completed.
Rifle light, Mark I, white:				
Unexcelled Manufacturing Co	P3271-1125TW	Feb. 22, 1918	265,000	(1)
Lewis Nixon	P3856-1291TW	Mar. 8, 1918	55,000	55,000
Signal lights, Mark I, green:				
Unexcelled Manufacturing Co	P3272-1126TW	Feb. 22, 1918	88,000	(1)
Lewis Nixon	P3856-1211TW	Mar. 8, 1918	55,000	55,000
Mark I, red:				
Unexcelled Manufacturing Co	P3272-1126TW	Feb. 22, 1918	88,000	(1)
Lewis Nixon	P3856-1291TW	Mar. 8, 1918	55,000	55,000
Total			606,000	165,000
VB parachute:				
Lewis Nixon	P3856-1291TW	Mar. 8, 1918	610,000	53,040
VB star cartridge:				
Lewis Nixon	P3856-1291TW	Mar. 8, 1918	605,000	174,420
Total			1,215,000	227,460

[1] Canceled.

SIGNAL LIGHTS, MARK II, VERY.

On January 3, 1918, contracts were let for Remington Arms Co. U. M. C. for 1,000,000 signal lights, Mark II, except stars, and to the National Fireworks Distributing Co., for 1,000,000 stars. These contracts were completed and production well under way on 2,000,000 more, when on May 18 we were notified that the 10 gauge pistol, the ammunition for which is the signal lights, Mark II, would be replaced by the 25 mm. French type pistols. Production was stopped immediately. The contracts let with production accepted by Government inspection up to December 12, 1918, are as follows:

Article and firm.	Contract No.	Date.	Contracted for.	Completed.
Red, Mark II:				
Remington Arms Co	G1802-636TW	Jan. 2, 1918	333,000	307,800
Do	P2473-871TW	Feb. 1, 1918	667,000	576,980
Total			1,000,000	884,780
White, Mark II:				
Remington Arms Co	G1802-636TW	Jan. 2, 1918	334,000	330,400
Do	P2473-871TW	Feb. 1, 1918	666,000	615,480
Total			1,000,000	945,880
Green, Mark II:				
Remington Arms Co	G1802-636TW	Jan. 2, 1918	333,000	294,600
Do	P2473-871TW	Feb. 1, 1918	667,000	425,748
Total			1,000,000	720,348
Grand total			3,000,000	2,551,008

VERY CARTRIDGES, 25 MM.

Contracts were let first for 25-mm. Very cartridges on August 17, 1918. The primed metal cartridge cases were made by one manufacturer and sent to a fireworks plant to be loaded. The Government furnished primers, silk parachutes, metal parts, and in order to facilitate production, it was intended to furnish the loading plant all component parts. Production was well under way on component parts when the armistice was signed. Contracts let with production accepted by Government inspectors to December 12, 1918, were as follows:

Article and firm.	Contract No.	Date.	Contracted for.	Completed.
1 star, red: National Fireworks Co	P15172–2506TW	Sept. 19, 1918.	100,000	0
1 star, white: National Fireworks Co	P15172–2506TW	do	100,000	0
1 star, green: National Fireworks Co	P15172–2506TW	do	100,000	0
Total			300,000	
Cartridge cases: Empire Art Metal Co	P13873–2372TW	Aug. 21, 1918.	2,000,000	836,010
No. 4 commercial primers: Winchester Repeating Arms Co	P15519–2543TW	Sept. 27, 1918.	25,000,000	4,760,000
24-inch silk parachutes:				
New England Corset Co	P17024–2727TW	Oct. 24, 1918.	500,000	0
Rose Bros. & Co	P15187–2508TW	Sept. 20, 1918.	100,000	65,600
Total			600,000	65,000
Metal star containers: Art Metal Works	P16105–2630TW	Oct. 3, 1918.	5,200,000	10

SMOKE TORCHES.

On June 25, 1918, contract was let for 500,000 smoke torches. The first production was not satisfactory, but after several experiments were made, a successful mixture was accomplished. An improvement was made in the tin can. Production accepted by Government inspectors up to December 12, 1918, was as follows:

Article and firm.	Contract No.	Date.	Contracted for.	Completed.
Smoke torches: Nixon Fulgent Products Co	P10700–2114TW	June 25, 1918.	500,000	110,000

WING-TIP FLARES.

The first contract was let August 27, 1918, to Henry J. Paine for 20,000 red and 20,000 white wing tip flares. Considerable delay was caused making a mixture that would give the proper time of burning. A contract was let on June 1, 1918, to Nixon Fulgent Products Co., who were able to meet the specifications. A successful formula was given to Henry J. Paine so that production could proceed without further delay. The contracts let with production accepted by Government inspectors up to December 12, 1918, are as follows:

Article and firm.	Contract No.	Date.	Contracted for.	Completed.
Mark I. red:				
Henry J. Paine	P8741-1971TW	May 27, 1918	20,000	0
Lewis Nixon	P9062-1990TW	June 1, 1919	36,083	36,083
Total			56,083	36,083
Mark I. white:				
Lewis Nixon	P9062-1990TW	June 1, 1919	36,082	36,082
Henry J. Paine	P8741-1971TW	May 27, 1918	20,000	8,000
Total			56,082	44,082

AIRPLANE FLARES.

On May 29, 1918, a contract was let to the Nixon Fulgent Products Co. for assembling of 50,000 airplane flares. The metal casing or bomb, was let to Edward G. Budd Manufacturing Co., Philadelphia, on June 5, 1918. The Government also furnished silk for the parachutes and contracted for the making of the parachutes. Considering the large amount of detail involved, good progress was made in securing silk for the parachutes, making of the parachutes, and the making of metal cases. It was necessary to make several changes in the loading or assembling before the flares would function properly. The contracts let with production accepted by Government inspectors up to December 12, 1918, are as follows:

Article and firm.	Contract No.	Date.	Contracted for.	Completed.
Silk for airplane flares:				
Cheney Bros	P11934-2222TW	July 16, 1918	75,000	75,000
D. G. Dery (Inc.)	P12144-2340TW	do	200,000	147,153
Stehli Silk Corporation	P11894-2209TW	do	101,000	101,000
Sanquoit Silk Co	P11935-2223TW	do	42,000	38,705
Louis Roessel & Co	P11932-2220TW	do	75,000	40,279
Schwarzenbach, Huber Co	P9251-2006TW	June 4, 1918	30,000	30,000
	P9369-2019TW	June 6, 1918	50,000	50,000
	P9923-2059TW	June 13, 1918	50,500	50,500
	P10387-2084TW	June 21, 1918	[1] 25,000	25,000
	P10965-2134TW	June 28, 1918	112,500	112,500
	P11367-2160TW	July 6, 1918	450,000	394,428
	P13567-2354TW	Aug. 15, 1918	75,000	75,000
Duplan Silk Corporation	P11933-2221TW	July 16, 1918	[1] 100,000	92,171
Total			[1] 1,386,000	1,231,728
Parachutes for airplane flares:				
Duplan Silk Corporation	P8912-1982TW	June 5, 1918	1,000	1,000
Follmer, Clogg Co	P9960-2061TW	do	1,785	1,785
	P13629-2358TW	Aug. 16, 1918	2,000	2,000
	P14890-2482TW	Sept. 13, 1918	25,000	13,400
	P12161-2245TW	July 18, 1918	300	[2]
Jacob Gerhardt Co	P13787-2370TW	June 17, 1918	1,500	1,500
	P16313-2660TW	Oct. 13, 1918	10,000	6,094
	P10964-2133TW	June 28, 1918	1,800	1,800
Total			44,385	27,579
Metal cases for airplane flares: Edw. G. Budd Manufacturing Co.	P9321-2009TW	June 5, 1918	65,083	41,020
	P17796-2814TW	Nov. 1, 1918	[2]	
Assembling and loading:				
National Fireworks Co	P17584-2788TW	Oct. 30, 1918	15,000	[2]
Lewis Nixon	P8913-1983TW	June 29, 1918	50,083	3,600
Total			65,083	3,600

[1] Yards. [2] Canceled.

HISTORY OF THE PRODUCTION OF SIGNAL PISTOLS.

VERY SIGNAL PISTOLS, MARK III, 10-GAUGE.

The Remington Arms U. M. C. Co. was given contracts for 35,000 10-gauge Very signal pistols, of which 20,460 were completed when it was decided to change to the 25-mm. Very pistols, Mark IV. Production accepted by Government inspectors up to December 12, 1918, is as follows:

Article and firm.	Contract No.	Date.	Contracted for.	Completed.
Mark III, 10-gauge:				
Remington Arms Co.	G720-382TW	Nov. 13, 1917	12,500	12,500
	P5871-1176TW	Apr. 13, 1918	22,500	7,960
Total			35,000	20,460

25-MM. VERY PISTOLS, MARK IV.

On August 5, 1918, contracts were let for 135,000 25-mm. Very pistols, of which 15,000 have been passed by Government inspectors December 12, 1918:

Article and firm.	Contract No.	Date.	Contracted for.	Completed.
25-mm., Mark IV:				
A. H. Fox Gun Co.	P13029-2302TW	Aug. 5, 1918	33,057	4,193
National Tool & Manufacturing Co.	P13030-2303TW	do	75,000	0
Scott & Fetzer Machine Co.	P13031-2304TW	do	30,000	7,750
National Tool & Manufacturing Co.	P16311-2658TW	Oct. 13, 1918	28,662	0
Total			166,719	11,943

35-MM. VERY PISTOLS, MARK I, AVIATION.

Thirty-five-mm. pistols, Mark I, aviation, were contracted for the last of August, 1918. Production was well under way when the armistice was signed. Production accepted by Government inspection up to December 12, 1918, is as follows:

Article and firm.	Contract No.	Date.	Contracted for.	Completed.
Die cast parts:				
Dohler Die Casting Co.—				
Handles	P13578-2355TW	Aug. 16, 1918	31,152	5,258
Barrels	P13578-2355TW	do	31,152	4,931
Sides	P13578-2355TW	do	31,152	6,193
Locking piece	P13578-2355TW	do	31,152	4,347
Finished pistols:				
Hammond Typewriter Co.	P13325-2330TW	Aug. 10, 1918	15,000	0
Parker Bro.	P14453-2431TW	Aug. 29, 1918	14,669	0
Total finished pistols			29,669	0

APPENDIX.

TACTICAL USE OF FOREGROUND ILLUMINATION.

The illumination of the foreground is effected by several means, but the most effective is the searchlight.

TACTICAL USE OF SEARCHLIGHTS.

Considerations.—Depending upon whether the searchlight is used for reconnoitering the dispositions made by the enemy or for combating him, it takes part in the work of exploration or in the action itself. Apart from these two methods of employment, there exists hardly a means of utilizing it with a tactical object. The searchlight is the most effective auxiliary of fire at night. It surprises the enemy, blinds him, and renders him visible, under conditions which depend principally on the hygrometric condition of the air, the diameter of the searchlights, and on the angle of site. By its unforeseen appearance it contributes in delaying and in hindering the advance, and directly to nullify, the intentions of the assailant. The surprise is prepared by the securing of data of prominent points of the terrain during daytime, by means of a special oscillation and inclination device which permits of instantly directing the beam on the point marked.

Independently of the moral effect produced by the surprise, that caused by the dazzling power of the rays prevents the adversary from aiming and firing under good conditions, since it completely prevents him from observing and estimating distances. Furthermore, advance on the searchlight is very difficult. Oscillating illumination (change of direction of the beam from left to right and from right to left) or intermittent (light alternating with obscurity) causes loss of orientation and direction; horses are seized with panic, intrenching has to be suspended, and the enemy is often obliged to discontinue all movement.

* * * * * * *

Moonlight does not reduce as much as would be thought the use of the searchlight, the illuminating power of the searchlight being far greater than that of a full moon. There results an increase of visibility when the searchlight enters into operation. Field searchlights can furnish in normal weather the visibility of the naked eye, and consequently the vulnerability of the adversary at the following distances:

1. *Chemical light apparatus.*—Owing to their low illuminating power these apparatus can operate only with the use of a cylindrical beam. The useful range of these searchlights for the discovery of a group is at from 150 to 200 meters with the naked eye and 250 meters with a field glass. The width of the front illuminated by these apparatus is about 10 meters.

2. *Electric light apparatus.*—Thirty-six-inch electric searchlight, cylindrical beam: Group personnel, with naked eye 1,400 meters; with field glass 2,000 meters; isolated personnel, with naked eye 800 meters; with field glass 1,200 meters. With divergent beam: Group personnel, with naked eye 700 meters; with field glass 800 meters.

Sixteen-inch electric searchlight, cylindrical beam: Group personnel, with naked eye 800 meters; with field glass 1,400 meters; isolated personnel, with naked eye 600 meters; with field glass 800 meters. With divergent beam: Group personnel, with naked eye 500 meters; with field glass 600 meters.

Twenty-four-inch electric searchlight was also available, and later, searchlights up to 60 inches in diameter were available; but these later large types were more particularly designed for use in the rear areas for aircraft detection and illumination.

The distances above mentioned give the degree of visibility of the different diameters of field searchlights, supposing the illuminated troop to be standing and dressed in gray or light blue, the shining parts of the equipment being covered with cloth. At the kneeling position the visibility decreases by one-half; it decreases in still greater portions at the lying position.

* * * * * * *

Light and yellow colors appear white in the luminous beam, green appears yellowish; troops in white and very dark uniforms are easy to discover, for they are well detached

in the luminous beam; gray and light blue uniforms are difficult to distinguish on a green background.

The flashes of arms, tools, buttons, visors of caps render a command very visible. Lights from fires and lanterns are rather difficult to see when they are in the luminous beam.

A fine rain considerably diminishes the range of the searchlight; fog completely checks its action. The same applies to smoke.

Against the dazzling light the only protection is to wear black glasses.

Lowering of visors and leafy branches carried in front give but mediocre results and have the disadvantage of allowing the troops to be discovered by flashes. The eyes of horses appear in the beam like phosphorescent lights.

GENERAL PRINCIPLES ON THE USE OF SEARCHLIGHTS.

* * * * * * *

Long-range searchlights can be employed for the following purposes:

1. Support exploration and contribute to reconnoitering of the terrain.
2. Illuminate objects for fire.
3. Facilitate the march of columns.
4. Mask the movements of friendly troops.
5. Blind enemy searchlights.
6. Blind the adversary.
7. Deceive the enemy by feints.
8. Produce an effect of demoralization.
9. Illuminate work of all kinds.
10. Insure communication between distant detachments and secure for signaling.
11. Aviation.

* * * * * * *

ILLUMINATE OBJECTS FOR FIRE.

* * * * * * *

Artillery fire.—As soon as the object has been discovered, the commander of the battery has the fire prepared for such object, the beam of the searchlight remaining unmasked as little as possible, so as not to draw the fire of the enemy. On firing the salvo the searchlight unmasks for the time necessary for observing the fire and, if required, following the object.

Infantry fire (rifle or machine gun).—

Rifle.—

* * * * * * *

A searchlight engaged should not retire, even under a menacing pressure of the assailant, unless it receives order from the commanding officer of the troops to which it is assigned, the natural role being to illuminate to the last moment.

Machine gun.—

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The machine guns open fire each time the object is illuminated by the luminous beam.

FACILITATE THE MARCH OF COLUMNS.

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The searchlight can also illuminate a line of march, the troops marching in the shade by side of the beam.

Owing to the very sensible contrast between the shade and the light, it is difficult to observe, through the luminous beam, what is passing beyond. Searchlights can therefore be used to establish a sort of luminous screen, behind which the enemy can see nothing. For this purpose one or more searchlights are employed, which are placed more or less to the flank according to circumstances.

This method is employed particularly on flat terrain, but is not practicable in broken country or in mountainous country, since the searchlight has to be installed at the same height as the objects to be masked, and the enemy must not be able to discover them by passing above or below the luminous beam.

Another method, but one of delicate application, consists in moving the luminous beam before a troop advancing, to prevent the enemy discovering it.

Blinding the adversary.—It is impossible for troops in face of a searchlight beam to distinguish anything in the direction of the searchlight or in the neighboring directions. It is therefore possible to approach very closely to an enemy blinded in this manner without being seen, and cases may occur in which an attack with the bayonet can be immediately carried out. This effect is increased if the searchlight be oscil-

lated from side to side, and if a succession of violent contrasts be produced by shutting off the light and reestablishing it several times in succession. Troops marching under these conditions generally lose direction and get in disorder. This effect is still more marked with mounted troops.

Deceiving the enemy by feints.—The searchlights having been adjusted and put in action, the attention of the enemy is drawn in their direction, and this is taken advantage of to make a surprise attack from the opposite side.

Effects of demoralization.—The Russians are greatly in favor of this, for they noted these effects at the siege of Port Arthur. At night the men are in a state of nervous tension. When the luminous beam is thrown on them they are dazzled and think they are perceived by the enemy. This fear increases, for they are conscious of being unable to defend themselves, and thus feel their destruction imminent.

* * * * * * *

Communication between detachments—Signaling.—At night the luminous beam is visible at very great distances (12 to 62 miles,) according to its strength.

For signaling, the Morse signals or conventional signals are used. Another method consists in projecting the luminous beam on the clouds. Its trace is seen from a great distance (43½ to 50 miles).

In daytime the searchlight can replace the heliograph; in this case it has to be oriented.

Aviation.—According to aviators it appears that the zone lighted by the divergent lens is sufficient to enable a belated aeroplane to land without too great difficulty.

METHOD OF USE.

It is much more difficult to employ searchlights judiciously in an attack than in defense, for, while the defender will endeavor to explore and minutely search all the terrain in front of him, the assailant will seek obscurity to execute his movements and obtain surprise effects.

DISTRIBUTION OF SEARCHLIGHTS.

The conditions of a good distribution are that each zone of terrain be illuminated with sufficient intensity. It is according to this rule that, in certain foreign armies, the number of searchlights necessary is calculated at the rate of 1 for each 1,000 yards of front.

Searchlights are preferably employed in groups of two each—one for searching for objects, the other for keeping them illuminated and enabling the fire on them to be properly directed. It is thus possible to continue searching the terrain.

ACTION OF THE SEARCHLIGHT.

For searching the terrain it is necessary to operate by alternating light and obscurity, in order that an enemy can not see the beam coming upon it and have the time to avoid it. One should also operate by "bounds," the searchlight remaining unmasked only for the time necessary to allow the observers to see well the illuminated sector. A continuous illumination attracts the fire of the enemy infantry and artillery and facilitates their aim. By means of the sighting device for height and direction fixed on each searchlight, it will be easy to direct the beam instantaneously on a given point that has been marked during daytime. When troops are reported the surprise by the light and the surprise by the fire should be as simultaneous as possible; the adversary remains illuminated as long as the troops covering him with fire consider useful.

The use of the light of a searchlight as a rallying signal at the moment of shock and even during the action is to be condemned, for the friendly troops will almost always be illuminated the same as the enemy.

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To embarrass adverse ranging on the searchlight the same can be raised or lowered, varying the intensity of the light by combining changes and variations with periods of obscurity. In this manner changes of position of the searchlight can be simulated.

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The best position for observing is about 40 meters on the flank and a few meters to the rear of the searchlights.

If, in order to observe better, the officer observer has to advance, he will select a position situated at a lower height than that of the searchlight, so as to be always below the beam.

In case of necessity the officer observer may observe from the position of the searchlight, but must place himself below the cone of light.

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The observer should impress himself with the idea that the illumination of targets will be the most important task of the searchlight. The dazzling, which in certain cases may produce a considerable effect, will be but secondary.

* * * * * * *

The illumination of the foreground by means other than searchlights is accomplished by various contrivances.

Among those most often used are:

Portable lights (automobile headlights), usually electric, using storage batteries.

Rockets shaped like a cartridge, 6 inches long and 1 inch in diameter, fired from a sort of sawed-off shotgun, the light burning about 20 to 30 seconds.

Rockets, a good deal like those used for fireworks, fired from a tube and burning about three minutes.

Flares thrown to the front and so weighted as to stick in the ground upon landing, burning for varied lengths of time.

Rockets which are attached to parachutes and burn as they slowly descend.

Very lights, which burn about one minute.

Bengal flares.

Balls made of a magnesium compound which are lighted and then thrown to the front, burning about two minutes.

Ordinary torches or lanterns backed with reflectors.

Bonfires built by advance sentinels and lighted by them as they withdraw under pressure of the enemy.

These and other contrivances are used for the illumination of the immediate foreground and are effective at ranges from 50 to 300 yards. Some of the lights may be so arranged as to be tripped and lighted by the enemy as he approaches, or may be lighted by men in listening posts. They are of value only in illuminating the ground for the use of rifle and machine gun fire, and mainly are of use in defense only.

Their tactical use is governed by the condition and extent of the area to be illuminated and the amount of illumination desired or possible, especial effort being made to keep the enemy in the light and one's own troops as much as possible in the shadow.

The time, method, and extent of illumination by means of the above-mentioned methods is a tactical question to be decided by the immediate commanders.

It is to be observed that the agents employed in the illumination of the foreground will be largely governed by the conditions. A searchlight throwing a steady beam or intermittent flashes can be readily located by the enemy and will draw artillery fire. With a circular beam, for distance projection, its area of illumination is limited to the diameter of the beam of light. On terrain which is level or sloping toward the enemy positions, it will illumine friendly positions as well as enemy positions.

The position of chemical searchlights located near the front lines may be changed more readily than large electric searchlights, owing to the lighter equipment.

Flares illumine the general surroundings, rather than the specific objective.

Torches thrown out in front of the lines by hand illumine for a short period only, but additional torches can be thrown out if required.

Illuminating bombs are preferable to rockets, in that the trailing sparks of a rocket give indication prior to the bursting of the illuminating element, and thus give warning which may permit of enemy concealment prior to the burst.

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*599. Forward Illumination in Battle.

*601. Tactical Use of Foreground Illumination.

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*722. Description and Instruction for the Use of Position Lights, Mark I and Mark II.

739. Description and Instruction for the Use of Very Pistol, Mark III, and Signal Light, Mark II.
751. Hand Book of Signal Light, Mark I, and Rifle Light, Mark I.
798. Tactical Rocket for Small Units in Trench Warfare.
833. Description of Wing Tip Flare, Mark I.
*839. Description and Instructions for the Use of Smoke Torch, Mark I.

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F 43. French Pyrotechnics.
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* Obsolete or out of print.

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VOLUME I OF II

25 MILLION CANDLE CAST FLARE, DIAMETER AND BINDER STUDY
(Summary Report June 66 to June 67)

BERNARD E. DOUDA
U. S. Naval Ammunition Depot
Crane, Indiana 47522

Prepared under MIPR PG-6-58 for the Illumination Branch, Targets and Scorers Division, Air Force Armament Laboratory, Eglin Air Force Base, Florida

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(Summary Report June 66 to June 67)

BERNARD E. DOUDA

Prepared under MIPR PG-6-58 for the Illumination Branch, Targets and Scorers Division, Air Force Armament Laboratory, Eglin Air Force Base, Florida

This report was reviewed for adequacy and technical accuracy by Mr. W. S. Cronk, Mr. Larry Moran, and Captain Gene Holder, Eglin Air Force Base and Mr. Clarence Gilliam, NAD Crane.

Submitted by:

B H Calkins

B. H. CALKINS, Director
Research and Development Department

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ABSTRACT

The feasibility of making an illuminating candle which produces a luminous intensity of 25 million candles is demonstrated. The goal is achieved by igniting all surfaces of a star shaped cavity which is formed through the center of the candle. Two horizontally opposed flames are generated by this candle.

The relationship between candle diameter and the ability of that candle to generate light efficiently is reported. This study includes data for both pressed and cast candles and shows the effect of different binder types. A general degradation of efficiency is observed as the cast candle diameter increases from 4 inches to 24 inches. The pressed candle series shows a maximum near the 4 inch diameter with degradation to either side.

Silicone, epoxy-polyglycol, polyester, polysulfide, and various combinations of these binders are described as they are used to make candles for the diameter study and the 25 million candle flare. A study of flare compositions consisting of magnesium and sodium perchlorate, the latter being partially dissolved in various methacrylate monomers is reported. A limited environmental program for a 4.5 inch diameter candle cast in an aluminum candle case and the development of a liner system for that candle is described. A polyester-epoxy

binder is used successfully to make a cast candle whose luminous efficiency is comparable to a candle made by the conventional pressed method.

Flame orientation and flame size effects are described. Contrary to common opinion, it is shown that a small flame size rather than a large flame from a given candle diameter is associated with candles which produce light with high efficiency. The binder is shown to be a major factor in the generation of various flame sizes and thus strongly influences the candle efficiency.

INTRODUCTION

This exploratory development program was conducted between June 1966 and June 1967 for the Air Force Armament Laboratory, Eglin Air Force Base, Florida, under MIPR-PG-6-58. The main objectives of the program were twofold. One goal was to demonstrate the feasibility of making an illuminating candle which has a luminous intensity of 25 million candles. This is a five-fold increase over the intensity delivered by the BRITEYE candle. The second goal was to conduct a study of the relationships between the diameter of a candle and the efficiency of light production from that candle. Both goals were attained during the contract period.

To assist the reader, the report is divided into four parts. Part I deals with the 25 million candle flare, Part II with the diameter studies, Part III with binder studies, and Part IV with flame orientation and flame size effects. Although the report is divided for convenience, it is noteworthy that all phases of this work are interrelated; that is, information generated in any one part is also utilized in the other phases in

an effort to extract the maximum amount of data from a minimum amount of work and hardware expenditure. With these remarks, the reader is encouraged to view this work as an integrated program instead of four distinct tasks.

The report is bound in two volumes. The main body of the report is in Volume I. The Appendices are in Volume II. A Table of Contents, Abstract, and Introduction for the entire report has been inserted at the beginning of each volume for convenience.

PART I

25 MILLION CANDLE FLARE

Purpose

The purpose of this report is to describe the exploratory development effort which led to the fabrication of an illuminating flare candle which generates a luminous intensity of 25 million candles.

Chronological Approach

During the manufacture of a conventional illuminating flare, the composition is normally consolidated into the flare container at a pressure near ten thousand psi. Furthermore, when it is necessary to make flares with a large cross-sectional area, extremely large presses are required in order to achieve the 10,000 psi consolidation force. Thus, the size of the candle that can be made is often limited by the size of press which is available. For example, a press of about 200 tons is required to consolidate the composition into an 8-inch diameter flare. Larger flares require correspondingly larger presses.

Since the consolidation operation becomes more complex as the size of the equipment increases, it becomes increasingly attractive from an economical standpoint to eliminate the consolidation operation. This can be achieved if the composition is cast into the candle container instead of pressed. The casting method is the technique chosen to make candles in this program. Appendix I gives additional information about the flare composition and the flare manufacturing technique. Generally, the composition will

not flow and therefore is tamped at pressures near 50 psi. For purposes of this report, the process of tamping and later polymerization of the composition is what is known as casting a flare candle.

In an effort to attain outputs of 25 million candles, flares were made in the normal solid cylindrical shape. It was estimated that flares of sufficient diameter and size could be made which would provide the required 25 million candle output. When these flares were tested, they burned in cigarette fashion. Two important characteristics of the process became evident: First, the luminous intensity output was found to degrade as the diameter of the candle increased. At the start of this program this degradation function was not defined. A separate part of the program entitled "Diameter Studies" was started in the effort to define the function. That work is described separately. The other benefit that came from this phase of the work was the development of the techniques required to process the composition. During the manufacture of the solid candles, various mixing, tamping, and casting techniques were tried. In addition, different composition formulas were used. All of this led to the preparation of candles which performed reliably and predictably.

During the early phases it was learned that about five pounds of composition needed to be burned per second in order to generate luminous intensities of 25 million candles. This in turn requires the burning of large composition surface areas in order to obtain the desired output. Since this would require candles of extremely

large diameters, if they were made as a solid cylinder, another approach was taken. Candles were made which had a star-shaped cavity as shown in Figure 1. The purpose of the star cavity was to present a larger surface area for burning. This idea is based on computations developed for the burning of propellant grains of various star configurations. Representative computations are provided in Appendix II.

Candles with the single star cavity exhibited one undesirable trait: the combustion within the cavity and subsequent exhaust of the flame gases through the cavity opening provided a propulsion effect. This made the candle difficult to control during test. Secondly, candles with a shallow single-star cavity did not provide the necessary output. Accordingly, candles with deeper cavities were tested in the next phase.

When it was found necessary to make candles with deep cavities in order to burn five pounds of composition per second, it was decided to make two additional changes: first, instead of making the candle with a single star cavity, candles were made with a star shaped cavity completely through the center of the candle as shown in Figures 2 and 3. Clearly then, when the candle is ignited, the flame can exit from both ends of the candle. This will give equal but opposing forces thereby eliminating the propulsion effect described earlier. Secondly, it was decided to suspend the candle in a horizontal position which causes the flames to develop horizontal to the surface of the ground. In this manner, a larger projected cross-sectional surface area of the flame is

CANDLE
WITH STAR SHAPED CAVITY

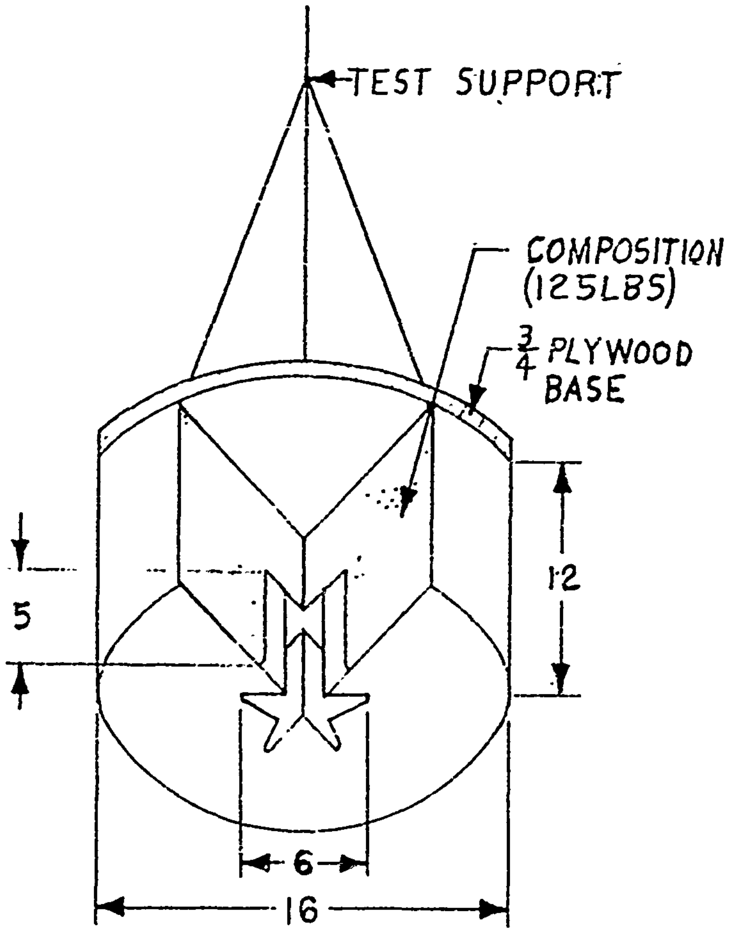

Figure 1: Sketch of single-star-cavity candle
This design was used for candles MAPI 300, 342 and 343.

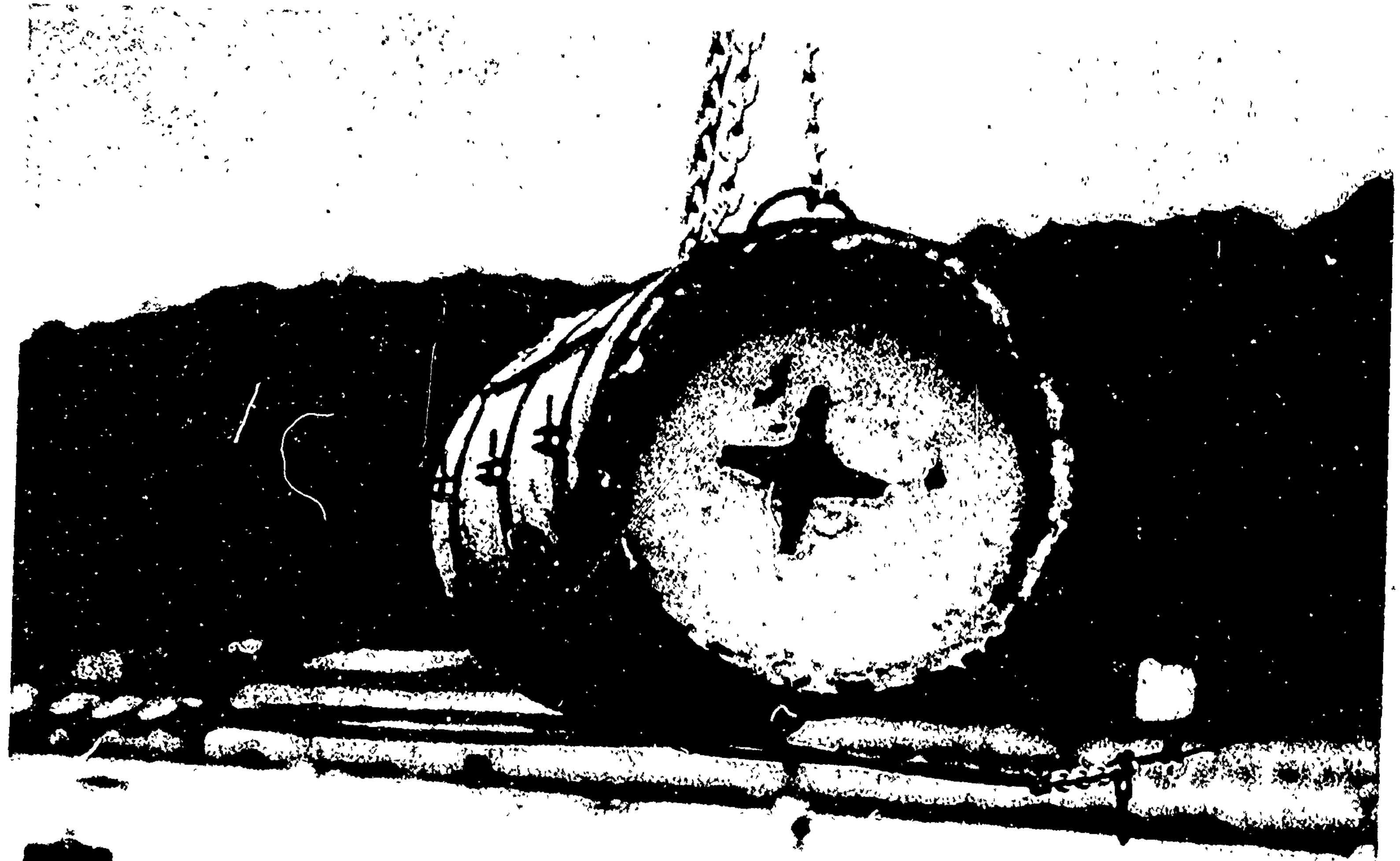

Figure 2: View of suspended double-star cavity 16 inch diameter candle

Figure 3: End view of suspended double-star cavity 16 inch diameter candle.

presented to the ground surface. This double star candle design was used successfully to generate the required luminous intensity of 25 million candles.

Experimental

All of the candles were tested at the MAPI site. In general, the MAPI site may be described as a polar arrangement of about 62 photocells on the ground each of which views the candle suspended about 80 feet in the air. Figure 4 is a schematic of the photocell layout. The cells are arranged such that the flare is viewed from all aspects. The cells numbered DS-1 through DS-8 are not located on the same scale in Figure 4 as the remaining 56 cells. Cells numbered DS-1, DS-3, DS-5, and DS-7 are 300 feet away from the flare whereas cells DS-2, DS-4, DS-6, and DS-8 are 200 feet away from the flare. These eight cells were added to the MAPI system during this program. The cells were placed at the greater distances in order that the entire flame could be viewed by the cells. Additional details about the MAPI site may be found in references (1), (2), (3), and (4).

Tables I and II are summary sheets for single and double star cast flares. Additional test data about each of these flares is provided in Appendix III, which is the numerical analysis of the data recorded during the test.

Discussion

The 25 million candle output requirement was demonstrated by both candles MAPI No. 426 and MAPI No. 463. In each case from Table II is is apparent that about five pounds a second of compo-

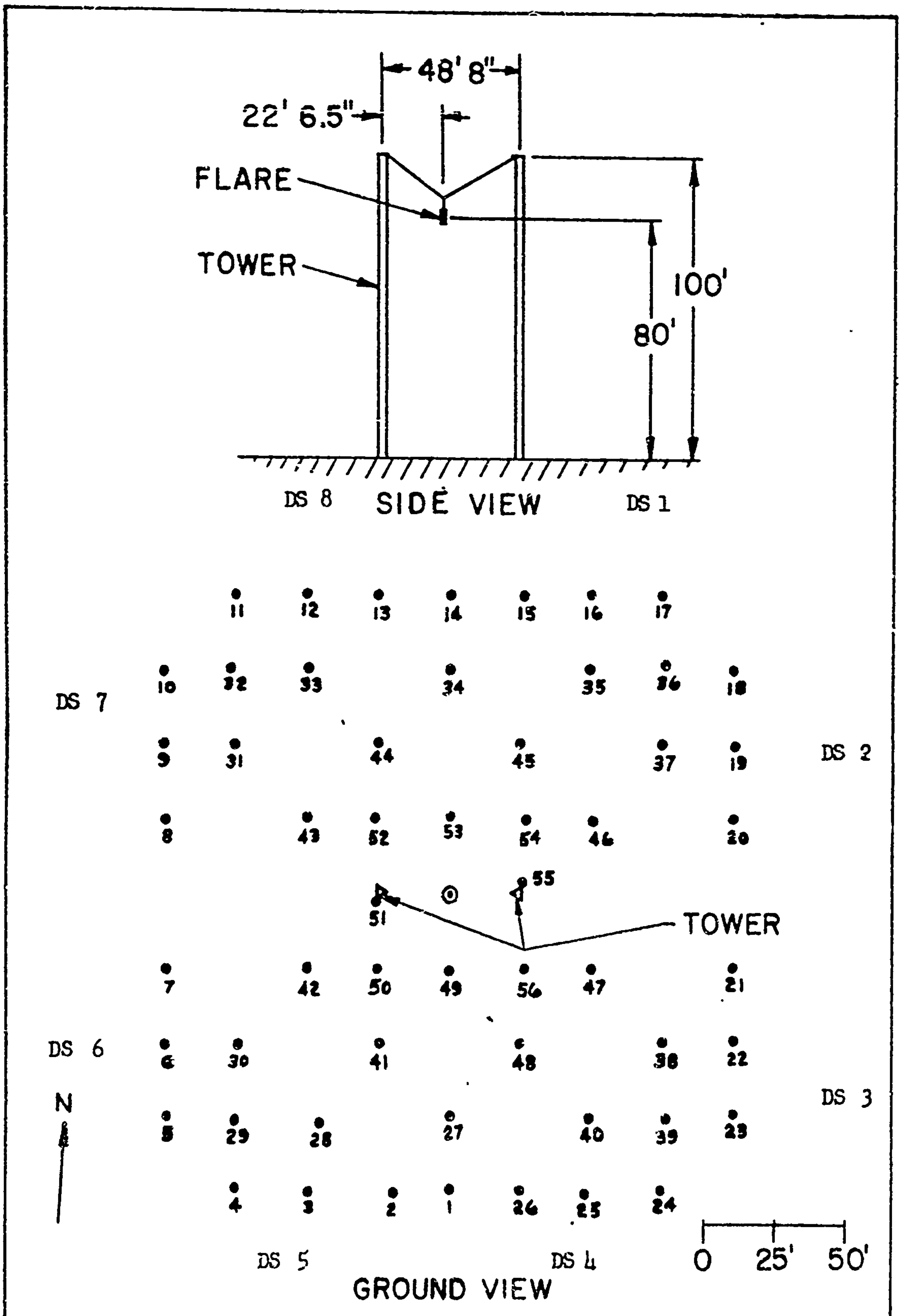

Figure 4: Plot plan of photocells showing their location in relation to the test towers.

TABLE I

16.0" DIAMETER SINGLE-STAR FLARE — 12 September

MAPI Test No.	300	342	343
Magnesium %	56.8	58.4	58.4
(granulation)	(15)	(15)	(17)
Sodium Nitrate%	28.8	28.8	28.8
(particle size)	(150μ)	(150μ)	(150μ)
Binder* %			
Silicone	14.4	12.8	12.8
Luminous Intensity ($x10^6$cd)	11.4	14.0	9.4
Burning Time (sec)	62	47	69.4
Efficiency ($x10^3 \frac{cd\text{-}sec}{g}$)	12.8	11.3	11.9
Burning Rate (in/sec)	0.05	0.16	0.07
Burning Rate (sec/in)	12.5	6.3	13.0
Burning Rate ($x10^3$g/sec)	0.9	1.2	0.8
Composition Weight ($x10^3$g)	56.7	56.7	56.7

* Silicone formula: Sylgard 182 plus curing agent.

TABLE II

16.0" DIAMETER DOUBLE-STAR CAST FLARES   12 September 1967

MAPI Test No.	394	426	427	463	464	556
Magnesium %	56.8	56.8	56.8	56.8	56.0	35.1
(granulation)	(17)	(15)	(17)	(17)	(15)	(15)
Sodium Nitrate %	28.8	28.8	28.8	28.8	29.0	49.9
(particle size)	(150μ)	(150μ)	(150μ)	(150μ)	(150μ)	(150μ)
Aluminum Chaff %					1.0	1.0
Binder* %						
Silicone	14.4	14.4	14.4	14.4		
Epoxy-Polyglycol					14.0	14.0
Luminous Intensity ($x10^6$cd)	15.1	25.0	18.0	24.3	13.6	6.5
Burning Time (sec)	37	36	48	49	93	93
Efficiency ($x10^3$ $\frac{cd\text{-}sec}{g}$)	10.1	11.1	10.7	9.8	15.5	7.4
Burning Rate (in/sec)	0.13	0.13	0.10	0.10	0.05	0.05
Burning Rate (sec/in)	7.6	7.2	9.7	9.9	18.7	18.7
Burning Rate ($x10^3$g/sec)	1.5	2.2	1.6	2.4	.87	.87
Composition Weight ($x10^3$g)	56.7	81.6	81.6	122.5	81.7	81.7

* Silicone formula: Sylgard 182 mix.
Epoxy-Polyglycol formula: 62% QX 3812 and 38% DER 732.

sition is burned. Also, the tables show that efficiencies in (cd-sec)/g generally range from ten to twelve thousand. This is only about one-fourth of the efficiency achieved when compared to the standard pressed illuminating composition in a four-inch size. Although these efficiencies are low, it is suggested that they might be improved considerably by utilizing more efficient binder systems or by improvement of the manufacturing techniques. In any event, the binder systems and techniques used did provide a means for the preparation of a candle whose output achieved the required 25 million candle luminous intensity.

Two other interesting observations were made. First, it was noticed that the luminous intensity was a direct function of the amount of flare composition burned per unit time. This relationship is shown in Figure 5. Secondly, a relationship between flame surface area and luminous intensity of the flare may be a direct function of the surface area of the flame projected toward the photocells as shown in Figure 6. It is suggested that this relationship is valid for a given composition formula in combination with particular candle geometry. On the other hand, these characteristics should not be interpreted that the flame is solely a surface emitter. Additional discussion and data regarding this point may be found in Part IV.

Two different binder systems are shown in Table II as being utilized to make the double star candles. The silicon resin system has the characteristic of burning much faster than does

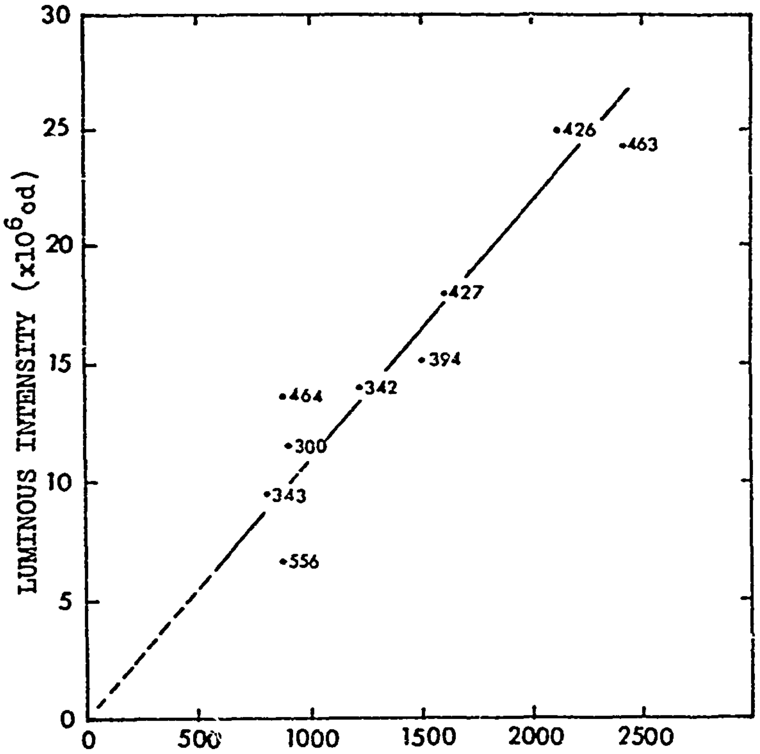

Figure 5: Luminous intensity vs composition consumption rate. Shows that at given efficiency, about 5 pounds of flare composition needs to be burned per second in order to achieve an intensity of 25 million candles. Numbers on data points are the candle MAPI test numbers.

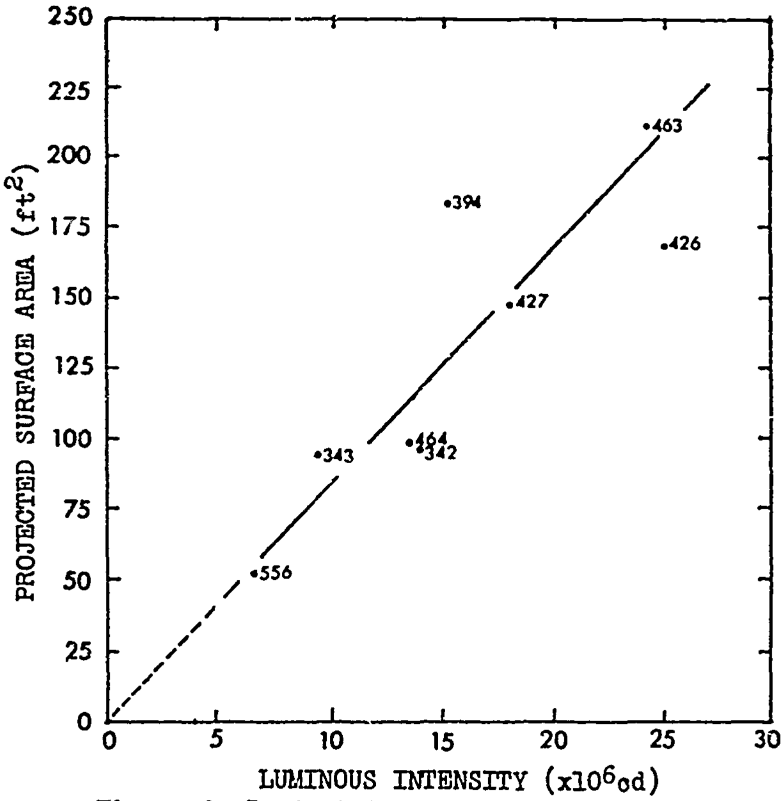

Figure 6: Projected surface area of the flame vs the luminous intensity. Shows that candles with either a single or double star shaped cavity and made with either an epoxy-polyglycol or silicone binder all exhibit the same behavior (linear to first approximation). Numbers on data points are the candle MAPI test numbers.

the epoxy-polyglycol system for comparable composition formulas. Both of these resin systems have the very desirable characteristic of a very low exotherm during the polymerization reaction. Generally, their pot life is about eight hours which permits adequate time for the casting process. After the candle is cast, it is placed in an oven at around 150-170°F for 24 hours or more to cause the cure. During this curing period, the exotherm is almost unnoticeable. This characteristic is extremely important from a safety standpoint, in particular when it is necessary to cure large section candles. Because the exotherm is extremely low, there is no danger of exceeding the decomposition temperature of any of the flare ingredients.

Conclusion

It has been demonstrated that a luminous intensity of 25 million candles can be delivered by a pyrotechnic illuminating flare. The information gathered during this phase of the program suggests that considerable improvement can be made by increasing the efficiency of this system. It is suggested that the efficiency increase can be achieved through the use of more efficient binder systems or through improvement of the processing and manufacturing techniques.

PART II
DIAMETER STUDIES

Purpose

The purpose of this work was to determine the relationship between the luminous efficiency of a flare and the flare's diameter. In this program, the flares were all end-burning, solid units, fabricated in paper cases.

Chronological Approach

The experiment was originally designed to include only flares that were consolidated at around 8000-9000 psi. Three composition formulas were selected for comparison at varying candle diameters. The diameters chosen were 1.76 inches, 2.66 inches, 4.25 inches, and 7.35 inches. The latter two sizes correspond to the MK 24 parachute flare and the BRITEYE flare, respectively. All of these flares were to contain 5% polyester (Laminac) binder and magnesium at 55%, 62% and 70%. The remainder of each formula consisted of sodium nitrate of an average particle size of 30 microns.

About this time, a cast flare program was being conducted concurrent with the binder study. Thus, it was convenient to extend the binder study to include a cast series of candles. This segment of the program included cast flares which ranged from 4.25 inches to 24 inches in diameter. Because four different binder materials were conveniently available, it was decided to make a diameter series with each of the four binder types.

One of the binder types chosen was a polyester (Laminac). This system was chosen to permit direct comparison to the pressed polyester series. Other systems chosen were the polysulfide, silicone, and epoxy resins. These resins were chosen to represent a wide diversity of types. For example, included are carbon backbone materials as well as sulfur and silicon backbone materials. The carbon types include both the polyester and the epoxy systems.

At this point it was learned that certain binder systems would perform reasonably well when consolidated at reduced pressures. For example, consolidation pressures of 2,000 to 3,000 psi were used instead of the

normal 8,000 to 9,000 psi. In a manner of speaking, these units, pressed at medium pressure are a cross between high pressure consolidation and casting. For this reason, this group of low pressure pressed units is called the "hybrid" series.

Units of the hybrid series were made in the 2.66 inch-, 4.25 inch-, and 7.35 inch-diameter sizes. The consolidation pressure was chosen such that the 7.35 inch-diameter size could be consolidated using a 60-ton press instead of the 200-ton press. The latter capacity is needed when consolidation pressures near 10,000 psi are required.

In summary then, the diameter study consists of a series of candles pressed at the 8,000 to 9,000 psi level, the hybrid series consolidated at 2,000 to 3,000 psi, and the cast series made with a tamping pressure of about 50 to 60 psi. The range of sizes of the candle is from 1.76 inches diameter to 24 inches diameter. All of the candles were made in the solid cylindrical configuration. That shape burns in cigarette fashion.

Experimental

Figure 7 shows the matrix of the diameter study for the candles consolidated at about 8,000 psi using a polyester as a binder. Figure 8 shows the matrix of the diameter study for the hybrid and cast series. The numbers in the matrices identify the candle.

The data collected from these test flares have been summarized in tabular form. The test data for each of the candles in the pressed and hybrid series of the diameter study may be found in Appendix IV. Appendix V includes all of the summarized data for the cast series of flares.

The tremendous amount of data collected makes it difficult to comprehend. Accordingly, a series of graphs were made to assist the reader in visualizing the results of this study. A graph was made showing each of the three pressed series and the hybrid series. Another graph was made for each of the binder types in the cast series. Finally, a graph which is a composite of all of the cast series was prepared so that these curves could be compared directly. All of these graphs are included in Appendix VI. Finally, in an effort to

Composition Formula *

DIAMETER	A	B	C
1.76 inch	T-499, 502 T-2624, 2625 T-3375, 3376 T-3377, 3378	T-500, 503 T-2626, 2627 T-3379, 3380 T-3381, 3382	T-501, 504 T-2628, 2629 T-3383, 3384 T-3385, 3386
2.66 inch	MAPI 484, 493 MAPI 538, 547 MAPI 623 thru 626 T-11836 thru 11850 MAPI 645 thru 648	MAPI 487 MAPI 496 MAPI 541 MAPI 550	MAPI 490 MAPI 499 MAPI 544 MAPI 553
4.25 inch	MAPI 485 MAPI 494 MAPI 539 MAPI 548	MAPI 488 MAPI 497 MAPI 542 MAPI 551	MAPI 491 MAPI 500 MAPI 545 MAPI 554
7.35 inch	MAPI 486 MAPI 495 MAPI 540 MAPI 549	MAPI 469 MAPI 498 MAPI 543 MAPI 552	MAPI 492 MAPI 501 MAPI 546 MAPI 555

*Ingredient	Group A	Group B	Group C
Magnesium (granulation 18)	55%	62%	70%
Sodium nitrate (30μ)	40%	33%	25%
Polyester binder	5%	5%	5%

Figure 7: Matrix showing candles by diameter and formula which made up the pressed series in the diameter study.

FLARE TYPE

DIAMETER (INCHES)	PRESSED POLYESTER	HYBRID EPOXY	CAST SILICONE	CAST EPOXY	CAST POLYESTER	CAST POLYSULFIDE
1.76	SEE FIGURE 7					
2.66		609, 614 619, 640				
4.25		610, 615 620, 722	506 521	579, 587 588	578, 585 586	649, 650 651
7.35		611, 616, 621 641, 642, 643 644	465 505	469 470		
8.0				577, 584 607	576 583	652 653
12.0			504, 507 523	605 606		
16.0			203, 299, 370 371, 393, 424 467	383, 392 575	574	419, 421 422, 423
20.0			503	604		
24.0			502	603		

Figure 8: Matrix showing candles by diameter and type which made up the diameter study. Numbers are MAPI test numbers.

present all of the data from this study in composite form, all of the graphs were put together on a common scale. These curves are shown in Figure 9. In Figure 9 one can find all of the information generated from the diameter studies presented graphically for direct comparison of all test series in relation to each other.

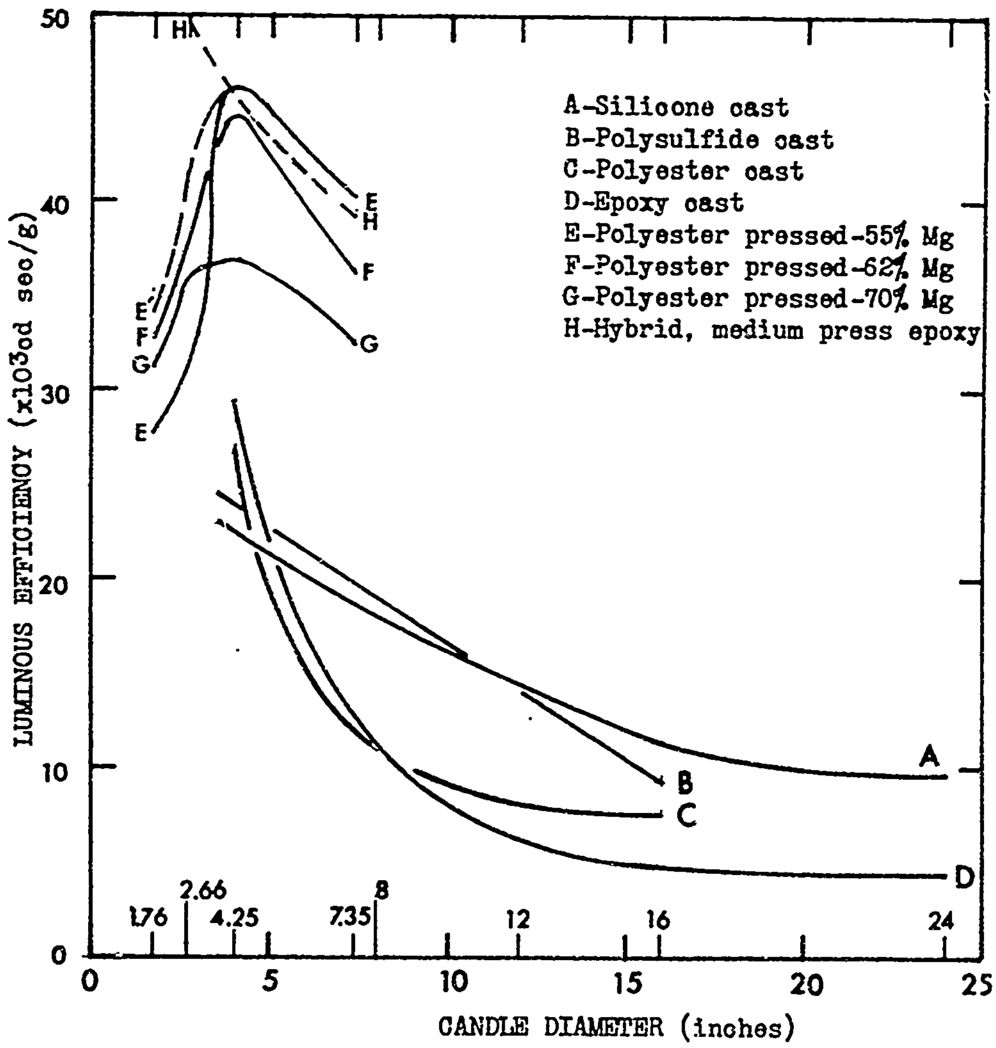

Figure 9: Luminous efficiency vs candle diameter. Shows behavior for end burning solid cylindrical candles with paper candle case all burned in vertical position on MAPI site with flame pointed downward.

Discussion

The data from the diameter studies is shown in Figure 9. The graphical presentation of the data disclosed some unexpected information which is part of the discussion which follows.

Let us first take a look at the pressed series of candles. This series is represented by curves E, F, and G. Generally, curves E, F, and G peak in the neighborhood of 4.25-inch diameter. The degradation of efficiency on the small diameter side of the peak seems to be more severe than it is on the large diameter side. On the other hand, this observation may be the result of experimental error. Another observation can be made as follows: Curve E, which represents the formula containing 55% magnesium, generally is more efficient than curve F, which is made up of a formula containing 62% magnesium. Both of these formulas are more efficient than group G, which contains 70% magnesium. It is therefore concluded that not only is the efficiency influenced by the candle diameter, but also the efficiency is a function of the magnesium to sodium nitrate ratio.

The pressed series in this diameter study were all made with the same binder; that is, a polyester. The three parts of the pressed series differ in the ratio of magnesium to sodium nitrate present in the formula. In another study described in reference 5, the silicone resin system was pressed in 4.25 inch diameter candles in a manner similar to the polyester candles in the pressed series of this study. The silicone resin was found to cause a gross degradation of the luminous intensity from these flares. With the use of this additional limited information to support the statement, it is concluded that the efficiency in the pressed series is not only a function of the candle diameter and the magnesium to sodium nitrate ratio as previously mentioned but also is a function of the binder type.

Curve E needs a little additional discussion. As presented, curve E intersects curves F and G on the small diameter side of the peak. This result was unexpected. Furthermore, the validity of this curve on the small diameter side of the peak is questioned. It is suggested that the curve should follow the dashed line represented by curve E'. The difference between curve E' and curve E on the small diameter side of the peak is believed to be due to instrumental error.

It is known that experimental data gathered in the photometric tunnel at Crane for a given candle is not numerically identical to experimental data from a similar candle tested at the MAPI site at Crane. It is from this situation that part of the difference discussed in the preceding paragraph may have originated. An additional source of error may have been introduced at the 2.66 inch diameter because these candles generate insufficient intensity to cause the photocells at the MAPI site to respond in their most accurate region. Nevertheless, an effort was made to present all of the data in Figure 9 on a MAPI equivalent basis. In an effort to obtain a conversion factor, 2.66 inch diameter candles, MAPI 623 through 626, and 645 through 648 were tested on MAPI, and candles T-11838 through T-11950 were tested in the photometric tunnel. A comparison of the data for these 2.66 inch diameter candles shows that the tunnel values multiplied by 80.2% yield the MAPI values.

Based on these tests, this conversion factor was used to convert data for all of the 2.66 inch- and 1.76 inch-diameter sizes which were burned in the tunnel to the MAPI equivalent. It should be emphasized once

again that although a conversion factor was obtained in this manner, the 2.66 inch-diameter samples tested at MAPI did not cause the photocells to respond in a desirable region and therefore it is not surprising that an error may have been introduced such that we observe curve E as intersecting with curves F and G instead of following the dotted line as E'. The latter would have been more reasonable.

Curve H on Figure 9 represents the hybrid series. Once again, the 2.66 inch-diameter size data is questioned in the light of the discussion in the preceding paragraph. On the other hand, because the deviation is gross, there is that possibility that an extremely high efficiency does, in fact, occur at the 2.66 inch-diameter.

The shape of the hybrid curve between 4.25 inch and 7.35 inch diameters can be compared directly to curve E. In this region, the two curves respond similarly. The fact that the hybrid series performs at almost equal efficiency to the series represented by curve E is most encouraging. This is particularly noteworthy inasmuch as no effort was made to optimize these compositions. It is suggested that if the composition were optimized, the hybrid series could be made to perform even more efficiently. In that eventuality it would then be feasible to convert production

to the low pressure consolidation method. This in turn would mean that the BRITEYE candle, for example, could be pressed with a 60 ton press instead of the 200 ton press now required. Production economies from this change would accrue immediately due to the tremendously decreased need for capitol investments and tooling.

Curves A, B, C, and D of Figure 9 represent the cast series of the diameter study. Curve A is the silicone resin, curve B is the polysulfide resin, curve C is the polyester resin, and curve D represents the epoxy resin compositions. The polysulfide series and the polyester series represented by curves B and C respectively, were introduced mainly for reference purposes. The processing properties of both of these materials are such that they are not very convenient to utilize. On the other hand, samples were included in order to provide information regarding their response relative to the silicone and epoxy resin types. It is interesting to note that the polysulfide system behaves rather similarly to the silicone system whereas the polyester system behaves more like the epoxy resins.

Both the polyester and the epoxy resins (curves C and D) perform exceedingly well with regard to efficiency at the 4.25 inch size. On the other hand, at the large diameters, these systems do not seem to perform as well as the silicone resin. Thus, it can be concluded that some resin systems are better than others at a given size. The corelary to this is that a binder which is superior at one size will not necessarily be superior at all sizes of candle diameter. This crossover of efficiency was not expected prior to the start of this study. It had been predicted that different binders would have different efficiency levels, but that the curves would run parallel to one another being separated by some constant.

The difference of behavior between the silicone resin and the epoxy resin may be due to one of the intrinsic properties of the resin itself. That is, for a given formula, it has been found that the flare composition made with the epoxy resin burns much slower than the composition made with silicone resin. It was therefore difficult to compare the two binder types directly even though all of the variables were kept constant except that of the burning rate. It is suggested that if a means could be found to make the epoxy composition burn faster without causing some other

interaction to occur, the flare composition made with the epoxy resin may then respond in a manner similar to that of the silicone resin. In an effort to accomplish this, aluminum staples were introduced in the composition to speed up the burning. No success was achieved with this approach nor was any other successful approach found. Until this burning rate difference can be resolved, the conclusions reached from this diameter study must be tempered with the knowledge that these combustion rate differences exist.

Conclusions

Several conclusions can be reached based on the information generated in the pressed series portion of the diameter studies.

a. The luminous efficiency is a function of the candle diameter, the magnesium to sodium nitrate ratio, and the binder type.

b. The luminous efficiency is optimum near the 4.25 inch diameter size, and degrades towards larger and smaller diameters.

These conclusions apply only to candles manufactured in a solid cylindrical shape, to candles which are end-burning and which burn in cigarette fashion, and to candles which are fabricated in paper tubes wherein the composition is pressed near 8000 psi.

If the same stipulations are imposed, except that the consolidation pressure is between 2000 and 3000 psi, we can conclude that the hybrid series responds with almost equal efficiency to the best of the pressed series. It should be noted that between 4- and 7-inch sizes, the difference between curve E and H is not statistically significant. It is suggested that further effort should be directed toward improvement of the hybrid series by optimization of the formula.

In most respects, the cast series of the diameter study exhibited the same characteristics as did the pressed and hybrid series.

a. A luminous intensity degradation is recorded over the entire range of candle diameters (4.25 through 24 inches). This characteristic is common to all of the four binder types.

b. At the 4.25 inch diameter candle size, the polyester and epoxy binders exhibit a higher luminous efficiency than do the silicone and polysulfide binders. At about the 5-inch candle diameter, all of the four binder types exhibit the same luminous efficiency. At candle diameters greater than five inches, the silicone and polysulfide binders show generally a higher efficiency than the epoxy and polyester binders.

c. The study shows that the luminous efficiency is a function of the candle diameter and the binder type. Based on limited additional data, the efficiency may also be a function of the magnesium to sodium nitrate ratio. Qualitatively, it is concluded that some types of binders are preferred at the small sizes, whereas, other types of binders may be preferable at large candle diameters.

Thus, no one binder type may be superior to all others over the entire range of candle sizes.

d. The conclusions are only valid for the specific binders used in this study. These data do not allow the conclusion that, for example, all silicone binders are superior to all epoxy binders.

The most important conclusion that arises from these data is that the performance is a strong and variable function of the binder type.

PART III
BINDER STUDIES

Purpose

This segment of the program was conducted in order to locate and evaluate various types of binders which might be suitable for casting illuminating compositions.

Approach

The approach taken to evaluate various types of binders is divided into three parts:

a. First, various epoxy resins and a silicone resin, each of which are commercially available, were evaluated for purposes of casting illuminating compositions.

b. Second, various oxidizing agents were dissolved into monomer systems in an effort to load the binder with oxygen. To the degree that this procedure is successful, the binder system can act not only as a binder but also as a source of oxygen supply. The dual role was expected to permit the formulation of more efficient illuminating compositions.

c. The third part resulted from an unsolicited proposal from the Thiokol Chemical Corporation (TCC). In that proposal, TCC described the preparation of a cast candle whose binder consisted

of a mixture of a polyester and epoxy resins catalyzed by iron linoleate.

Experimental

The casting of flares using the epoxy resin and silicone resin has been described in Parts I and II of this report. Generally, candles prepared with compositions containing the epoxy resin were superior when the candle diameter was relatively small. On the other hand, when candles of large diameter were tested, the silicone resin proved to be superior. In addition, there is a significant intrinsic burning rate difference between the two binder types when incorporated into an illuminating composition. That characteristic was also discussed earlier.

One of the efforts made to increase the burning rate of the epoxy system was the addition of aluminum chaff, sometimes called staples, to the illuminating composition. A similar application is described in reference 6, with regard to the casting of propellant grains. In this program, the burning rate was not increased noticeably by the use of staples. The use of staples is normally effective at binder concentrations in excess of 20%. On the other hand, most of the illuminating compositions studies were prepared with binder concentrations of 14% and less. Accordingly, this may explain why the staples were not effective.

Ordnance Research Incorporated Composition

The segment of the work performed in regard to soluble oxidizers was accomplished by Ordnance Research Incorporated (ORI). That work is described in its entirety in reference 7. The work at ORI started as an extension of the work described in reference 8. Generally, it was found that the methacrylate and acrylate monomers were excellent solvents for inorganic perchlorates of group 2 metals. Instead of using strontium perchlorate, the oxidant described in reference 8, sodium perchlorate was studied by ORI in various acrylate and methacrylate monomers.

During the evaluation of various monomers and the study of the illuminating composition formula, several noticeable characteristics of these materials were uncovered by ORI. Some of these are:

a. Because of superior combustion characteristics, magnesium remains the preferred metal over aluminum.

b. Sodium perchlorate was chosen as the oxidant because of its partial solubility in various monomers. Sodium nitrate would probably have been preferred if it were soluble to the degree that sodium perchlorate was found soluble.

c. Of the available acrylates and methacrylates,

glycidyl methacrylate was found to possess the most suitable combination of properties. Properties considered were: viscosity, vapor pressure, ability to dissolve the perchlorate, exotherm upon polymerization, and combustion characteristics.

d. Magnesium perchlorate and glycidyl methacrylate are hypergolic. Glycidyl acrylate is even more active than is the methacrylate.

e. Traces of acrylic acid or methacrylic acid found in some of the esters studied causes premature polymerization in the presence of magnesium.

f. The polymerization reaction is fairly exothermic. The pot life is rather short.

g. The optimization of the formula led to a 1 to 1 ratio of sodium perchlorate to magnesium and a binder content of about 15 to 16 percent. At this level, utilizing glycidyl methacrylate as the binder, the luminous efficiency of a free-standing grain is about 41,000 candle seconds per gram. The performance of this composition needs to be demonstrated in paper candle cases as well as aluminum candle cases. In addition, the composition needs to be compared to cast epoxy composition as well as the polyester composition developed by Thiokol Chemical Corporation.

The following general procedure is used by ORI to prepare the composition and cast a flare.

a. The proper amount of benzoyl peroxide is added to the measured amount of glycidyl methacrylate.

b. Sometimes Witco Ultrablend No. 11, a wetting agent, is added at this point.

c. Mix the solutions.

d. Add the perchlorate and mix. The duration of mixing should be sufficient to allow for a saturated solution of sodium perchlorate in the monomer to be achieved.

e. Divide the magnesium into three parts and add one part at a time with mixing in between.

f. Finally add the promoter and complete the mixing.

N, N, dimethyl p-toluidine is frequontly used as the promoter.

g. After the mix is completed, the composition is cast by tamping a mold as soon as possible. When polymerization is complete, the grains are subjected to a post-cure temperature of 75°C for 24 hours minimum.

h. The grain is removed from the mold. The exterior surfaces of the grain are inhibited with a polyester resin or similar material. All surfaces

of the grain on which combustion is not desired are inhibited.

i. These grains were normally tested by ORI in a face-up attitude. That is, the grain burns in cigarette fashion, starting from top to bottom, while producing a flame which extends upward from the top face of the candle.

Thiokol Chemical Corporation Composition

Another major contribution in the area of binder studies is that made by the Thiokol Chemical Corporation. The details of the entire program may be found in reference 9. As a result of their unsolicited proposal, the Air Force and the Navy entered into a joint contract with TCC for a limited environmental test program for castable flare compositions in the Mk 24 size. The purpose of this program was twofold: (1) to explore the feasibility of a cast composition and (2) to develop a liner system for use with this cast composition. In this program the candles were cast in aluminum tubes whose exterior dimensions are identical to the exterior dimensions of the Mk 24 paper candle tube (4.625 OD by 18.750 inches long). A liner is placed between the composition and the inside of the tube to provide a measure of insulation as well as to bond the composition to the aluminum case.

The composition formula which resulted from this work, was one which contained 9% of the binder, 61% magnesium and about 30% sodium nitrate. The 9% binder is broken down into about 7.37% of a saturated polyester binder "Foamrez F-17-80" as manufactured by the Witco Chemical Company and 1.53% of an epoxy resin identified as "ERL 0510" as supplied by Union Carbide

Corporation. A small amount of iron linoleate is utilized as a catalyst. See reference 9.

Generally, the ingredients for the TCC composition are processed in a conventional manner. The preblended binder is mixed with the sodium nitrate and magnesium until a homogenous mix is obtained. The composition is then tamped at about 60 psi into its container. It is later cured at a temperature of about 150°F for 60±12 hours.

It should be noted that the sodium nitrate must be processed under low humidity conditions. This is especially important for that fraction of the material which is very finely divided. In addition, high humidity conditions may cause difficulty in the preparation of the liner containing the polyurethane prepolymer. The B. F. Goodrich Chemical Company Product Data Sheet describes the polyurethane (Estane 5720X5) as a polyol reacted with a diisocyanate which is sensitive to water.

The ingredient particle size is also worthy of comment. In the case of both the sodium nitrate and the magnesium, a particle distribution is given in reference 9. Those sizes were chosen in an effort to achieve acceptable performance and high packing properties (density). The sizes should not be interpreted as being the optimum for this application. On the other hand, it is important to notice that judicious selection of the ingredients can contribute

immensely to one's ability to develop a candle whose performance has been optimized.

The liner which is placed between the composition and the aluminum tube consists predominantly of a polyurethane prepolymer impregnated into Kraft paper. Several insulation fillers and curing agents are added to this polymer in order to obtain the desired insulation, adhesive, and processing characteristics. The Kraft paper is coated with the liner mixture and then is cured for a minimum of 24 hours at approximately 150°F. When used, the liner is bonded to the aluminum case with a 2-inch wide strip of the liner mixture on the surface between the outside of the liner and the inside of the aluminum case. Just prior to casting the illuminating composition, the inside of the Kraft paper liner is again coated with the liner mixture and cured for approximately 4 hours at 150°F. The purpose of this operation is to obtain a tacky surface in order to provide a good bond between the liner and the flare composition.

At the base of the candle another liner mixture is used. That mixture consists principally of a carboxyl terminated polybutadiene polymer with some curing agents and fillers. That mixture is placed in the bottom of the aluminum tube as well as to assist in bonding the paper liner to the tube base.

When the case subassembly has been prepared as described, the composition is tamped in place at about 60 psi. When the casting is complete, the unit is placed in the curing oven.

TCC also performed a case bond stress analysis. The grain loading conditions considered were thermal shrinkage from 150°F to -65°F, and an axial acceleration of 25 g. The low temperature was assumed to be a uniform soak condition. The 25 g acceleration was a preliminary estimate of the parachute shock load. Further details of this stress analysis may be found in reference 9.

Of the more than 20 candles fabricated, 11 were tested on the Crane MAPI site. The individual data obtained from this test are tabulated in Table III. As reported in reference 9, several of the candles had been subjected to hot and cold shock, transportation and aircraft vibration sequences, and other environmental and durability tests.

The efficiency of the TCC cast candles is somewhat better than that recorded for standard MK 24 MOD 4 candles. During this contract, it was demonstrated that it is feasible to make an efficient cast illuminating candle in the MK 24 size when the candle case is aluminum. No study was made in regard to the performance of this cast composition in the MK 24 paper candle case.

TABLE III
Mk 24 Size Cast Candle(1)

MAPI	t_b (sec)	Intensity ($x10^6$ cd)	Efficiency ($x10^3$ cd-sec/g)	Burn Rate (in/sec)
627(3)	176	1.63	42.59	.0938
628	206	1.86	52.08	.0879
629	208	1.87	52.54	.0870
630	190	1.87	51.06	.0905
631	193	1.68	47.56	.0881
632	185	1.82	47.89	.0935
633	194	1.77	48.50	.0887
634	198	1.66	46.39	.0879
635	209	1.69	46.35	.0861
636	95(2)	2.97	35.75	.1916
637	180	1.88	46.77	.0961
639(3)	179	1.50	39.86	.0922

(1) Test on NAD Crane MAPI site, 6 July 1967. Intensity and burning times are from the computer printouts.

(2) Burned through side of case.

(3) These Mk 24 Mod 4 units had a composition length of 16.5 inches and a composition weight of 14.85 lbs.

Accordingly it is difficult to make direct comparisons between the TCC composition cast in aluminum tubes and the MK 24 composition pressed in paper tubes. However, the formula developed by TCC appears to have great potential.

PART IV
FLAME ORIENTATION AND FLAME SIZE EFFECTS

Purpose

During Parts I, II and III of the program, photographs were taken of the flame. This photographic data was analyzed and compared to the flare performance. The purpose of this segment of the report is to present that data.

Approach

During the diameter studies and binder studies, photographs were taken of the flame. The procedure for taking the photographs was to collect the image of the flame with a parabolic mirror and project it onto an easel. The image on the easel was photographed. In addition, the easel was calibrated for size in order to provide a means for estimating the size of the flame. Later the projected surface area of the flame was estimated by use of a planimeter. The surface area estimates were each plotted against the average luminous intensity of the parent flame. The resulting curve which gives an estimate of light output per flame surface area will hereafter be called an effective brightness curve. This phrase is used knowing that the data does not represent true flame brightness and that an exact brightness value cannot be obtained from the data collected in this program.

Discussion

It has long been known that the luminous intensity of a flame is some function of its size. The exact relationship, however, was not known. In the case of a flame resulting from the combustion of a given ratio of sodium nitrate to magnesium, it was usually postulated that the effective brightness is a constant. This can lead to the misleading conclusion that the luminous radiation can be increased simply by increasing the surface area of the flame. It is true enough that more light will usually be recorded from a flame whose size has been made significantly larger. On the other hand, it does not necessarily follow that this is the most effective approach to the problem of increasing the amount of light produced nor should it be assumed that the relationship is linear and independent of variables such as the binder type, the binder concentration, the ratio of fuel to oxidant, or the pressure used to make the candle.

As will be evident from the discussions which follow, a mere change in the binder type often results in a gross change in the effective flame surface area even when there is no change in the amount of binder in the formula or in the metal to oxidant ratio. Furthermore, the effective brightness function often is nonlinear as the flame size becomes larger even though all of the

flames in the series resulted from a composition which was not varied in regard to binder type or metal to oxidant ratio. To get larger flames in this situation, the candle diameter was increased.

The apparent nonlinearity needs to be discussed further. The nonlinearity always seems to progress toward a luminous intensity increase per unit of flame projected surface (increased effective brightness) as the size of the flame increases. This behavior might suggest that the flames become progressively more optically thick as they increase in size. Also, the recorded luminous efficiency of the flare in cd-sec/g is usually better when, from a given diameter candle, the effective brightness is high.

For purposes of clarity, the information will be presented in several segments. First, we will discuss that information which resulted directly from the diameter studies using only the polyester binder. These studies represent candles that were pressed at around 8000 psi. Next, we will present information concerning candles which were also pressed at around 8000 psi, but whose flare compositions contained either an epoxy binder or a silicone binder. And finally, information will be presented regarding the hybrid candles which were pressed at between 2000 psi and 3000 psi. All of this information about pressed candles will be compared

to candles prepared by the casting method.

In the cast series, data will be presented which compares candles containing polyester, epoxy and silicone binders. In addition, information will be presented to compare the flames from the candles cast in aluminum tubes by the Thiokol Chemical Corporation (TCC) to other cast candles. With the exception of the TCC series, all the test units whether pressed or cast were in a paper candle case.

Individual graphs of effective brightness of the flame are provided in Appendix VII for candles which were pressed at around 8000 psi with polyester, silicone, and epoxy binders. In addition, that Appendix contains the plot of the hybrid series which was pressed at around 2000 to 3000 psi.

Let us first consider data from the series consisting only of candles pressed with the polyester (Laminac) binder. The candles were made in two groups. One group was made in January, and the other group was made in March. Each group was made up of candles containing three different flare composition formulas. The formulas differ in respect to the magnesium to sodium nitrate ratio.

It was found that the January group showed generally a lower luminous efficiency than did the March group. The cause of this difference between two sup-

posedly identical groups has not been identified. Secondly, the candles containing 55% magnesium were always the most efficient within the group whereas the candles containing 70% magnesium were the least efficient in each group. As one can see in Figures 10 and 11, there is a remarkable correlation between luminous efficiency and effective brightness of the flame. Except for curve Q, which one would expect to be below curve P, the effective brightness graphs for each group form an order which is relatable to the magnesium percentage in the flare formula. This order is also the same as the order that luminous efficiency takes for the same units.

In Figure 10, for example, the 55% magnesium line (curve Q) represents an efficiency of about 42,000 cd-sec/g. The 62% magnesium line (curve P) represents an efficiency of about 40,000 cd-sec/g. Since both formulas produced about the same efficiency, this may explain why the curves are so near to one another. Also, because of experimental uncertainties, curve Q is found above curve P instead of below where one might have expected it to be. The curve with the least light output per flame surface (effective brightness) is represented by the 70% magnesium line whose efficiency is around 34,000 cd-sec/g. Thus, in this group of flares as well as the group shown in Figure 11, low efficiency

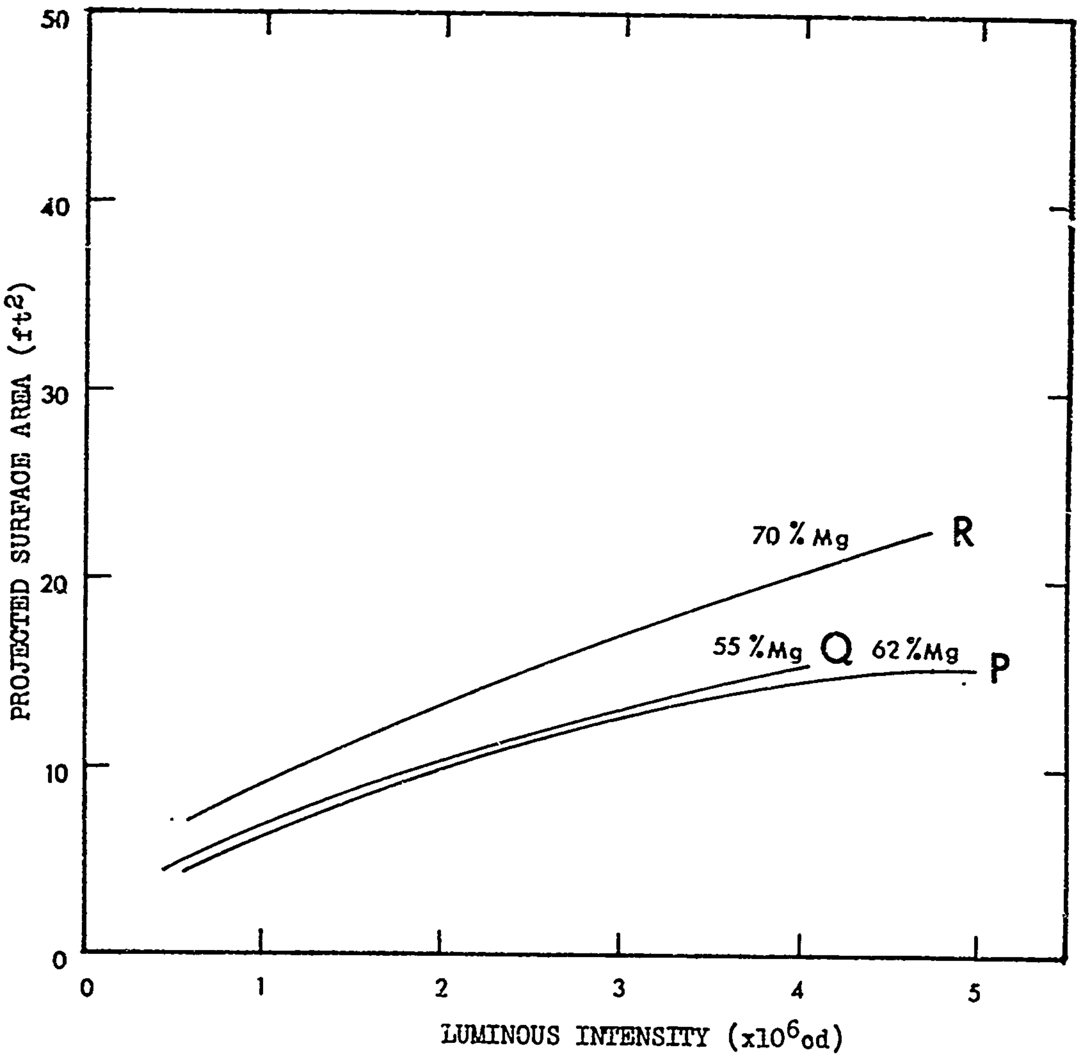

Figure 10: Effective Brightness Curves. Projected surface area of the flame vs luminous intensity for 2.66, 4.25, and 7.35 inch diameter candles pressed with 5% polyester binder and tested in January 67. High luminous efficiency (55% Mg) corresponds to high effective flame brightness (curve Q).

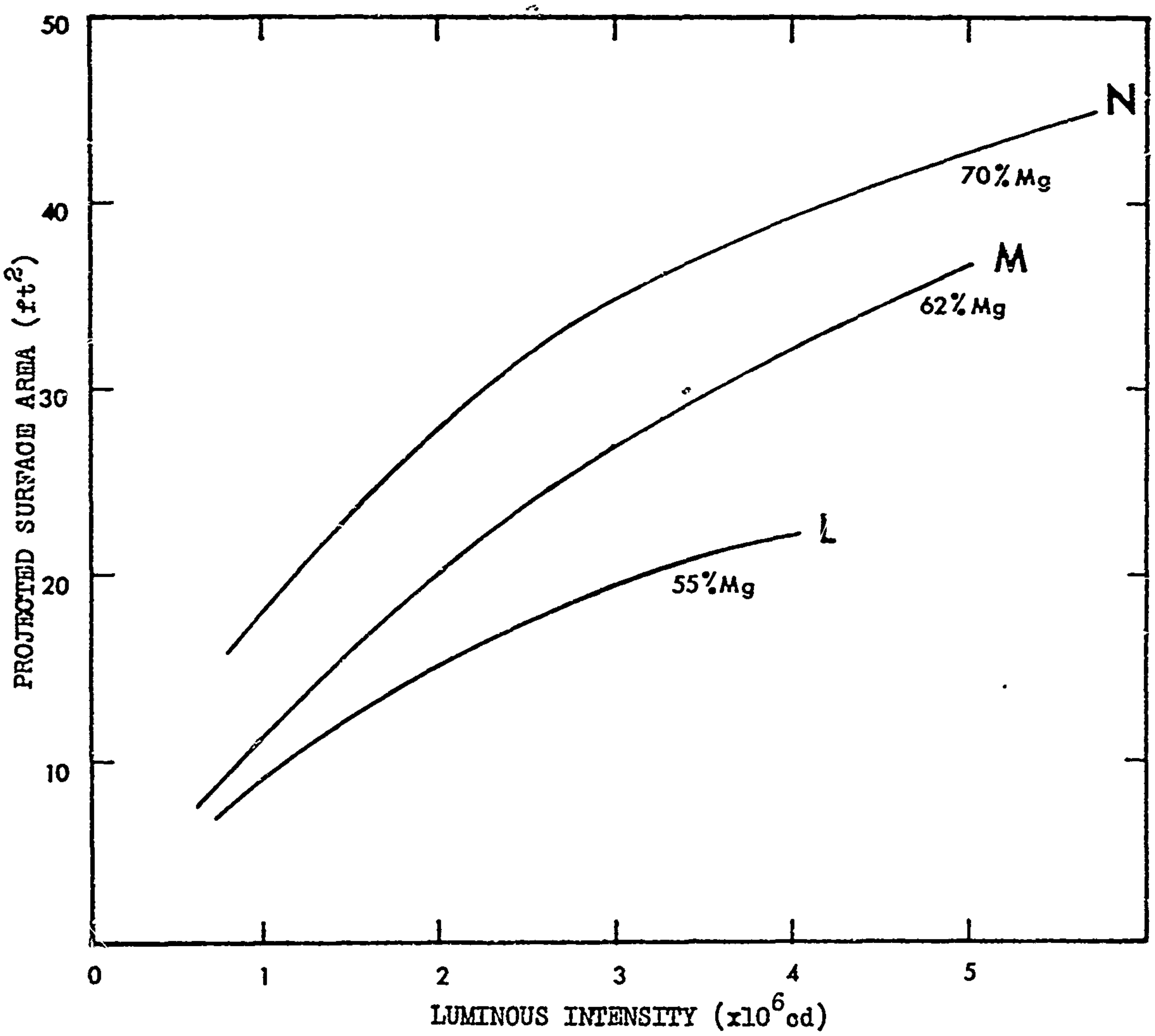

Figure 11: Effective Brightness Curves. Projected surface area of the flame vs luminous intensity for candles pressed with 5% polyester binder and tested in March 67. High luminous efficiency (55% Mg) corresponds to high effective flame brightness (curve L).

is associated with low effective brightness and high efficiency is associated with high effective brightness. Seemingly, for a given diameter candle, the flame with the smaller surface area is usually the more efficient.

By comparing the effective brightness curves in Figure 10 to Figure 11 and in view of the preceding discussion, one would conclude that all of the groups in Figure 10 should be more efficient than the groups in Figure 11 because the curves in Figure 10 all show a higher effective brightness for the flame. This is not the case. Generally, the groups in Figure 11 are more efficient. To find an explanation for what appears to be an inconsistency, one must utilize burning rate data tabulated for these candles in Appendix IV.

Comparison of the burning rate data shows a trend which explains why, on a diameter to diameter basis, all candles in Figure 11 produce a larger flame than candles in Figure 10. Generally, the Figure 11 candles burned significantly faster. Logically, this should produce more flame gases per unit time; hence a larger flame. Clearly then, burning rate is also a factor which must be dealt with when one attempts to draw conclusions from the effective brightness data.

Having completed the discussion of the effective brightness curves for the pressed candles with poly-

ester binder, we will now compare the best of that series (curve L) to pressed candles with other binders. For these comparisons, one should refer to Figure 12.

In Figure 12, the L curve is the same as the L curve in Figure 11 and is the effective brightness curve for candles pressed with a polyester binder. Candles pressed with epoxy binder are represented by the K curve and those with a silicone binder by the J curve. The hybrid series is shown by the H curve.

Comparison of the curves in Figure 12 leads to the same general conclusions reached during discussion of the data in Figure 11. Candles pressed at about 8000 psi with polyester binder (curve L) form a curve which is remarkably similar to the K curve which represents candles pressed at about 8000 psi with an epoxy binder. Each of these series have about the same luminous efficiency. Although the hybrid candles also had about the same luminous efficiency, the effective brightness curve H for these units behaves somewhat differently. It is suggested that this difference may be associated with the lower consolidation pressure (about 3000 psi) at which these units were made.

The J curve for candles pressed with a binder containing silicon is included for reference. Candles from this series show an efficiency about 25% less than the other series. The J curve may be unreliable because

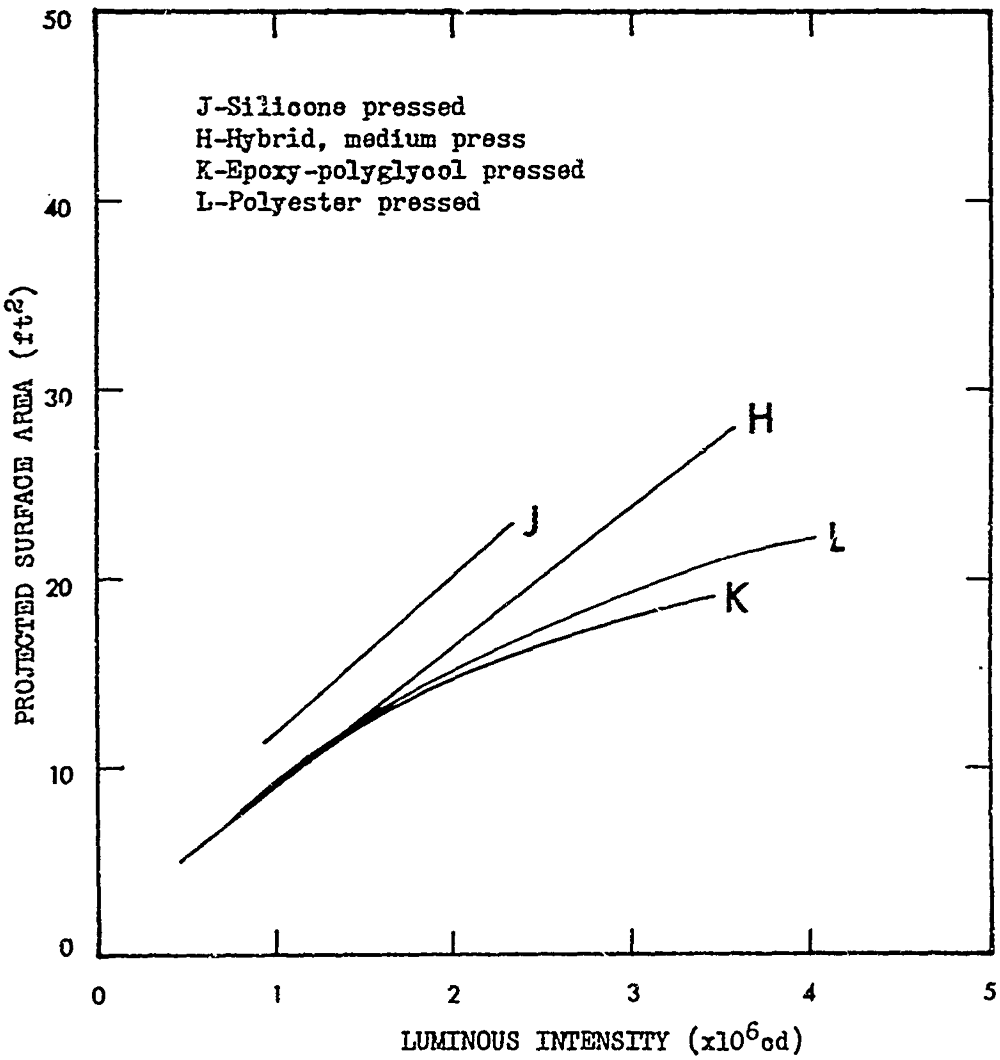

Figure 12: Effective Brightness Curves. Projected surface area of the flame vs luminous intensity for candles pressed with various binder types. High luminous efficiency (epoxy and polyester) correspond to high effective flame brightness (curve K and L).

it is drawn using only 5 data points.

Next let us compare the effective brightness curves for the cast series by binder type. See Figure 13. Individual curves have been plotted for each binder type. These may be found in Appendix VIII. We observe that curves V and W exhibit a low effective flame brightness. For these units cast with a polyester or epoxy binder, this corresponds to the low efficiency as shown earlier in Figure 9. The most efficient of the three binder types was the silicone resin which also has a high effective flame brightness (curve S). A fourth curve has been included for reference. That curve (T) contains information gathered from the TCC flares (see Part III) prepared with a polyester-epoxy binder in an aluminum tube. These candles, which were very efficient, also exhibit a high effective flame brightness. Except to generally show that high efficiency is relatable to a high effective brightness, one should not attempt to draw additional conclusions from the TCC flare data because of the different case material used in these candles.

The conclusion reached earlier for the pressed candles also seems to be valid for the cast candles. Once again, a high effective brightness is relatable to high luminous efficiency.

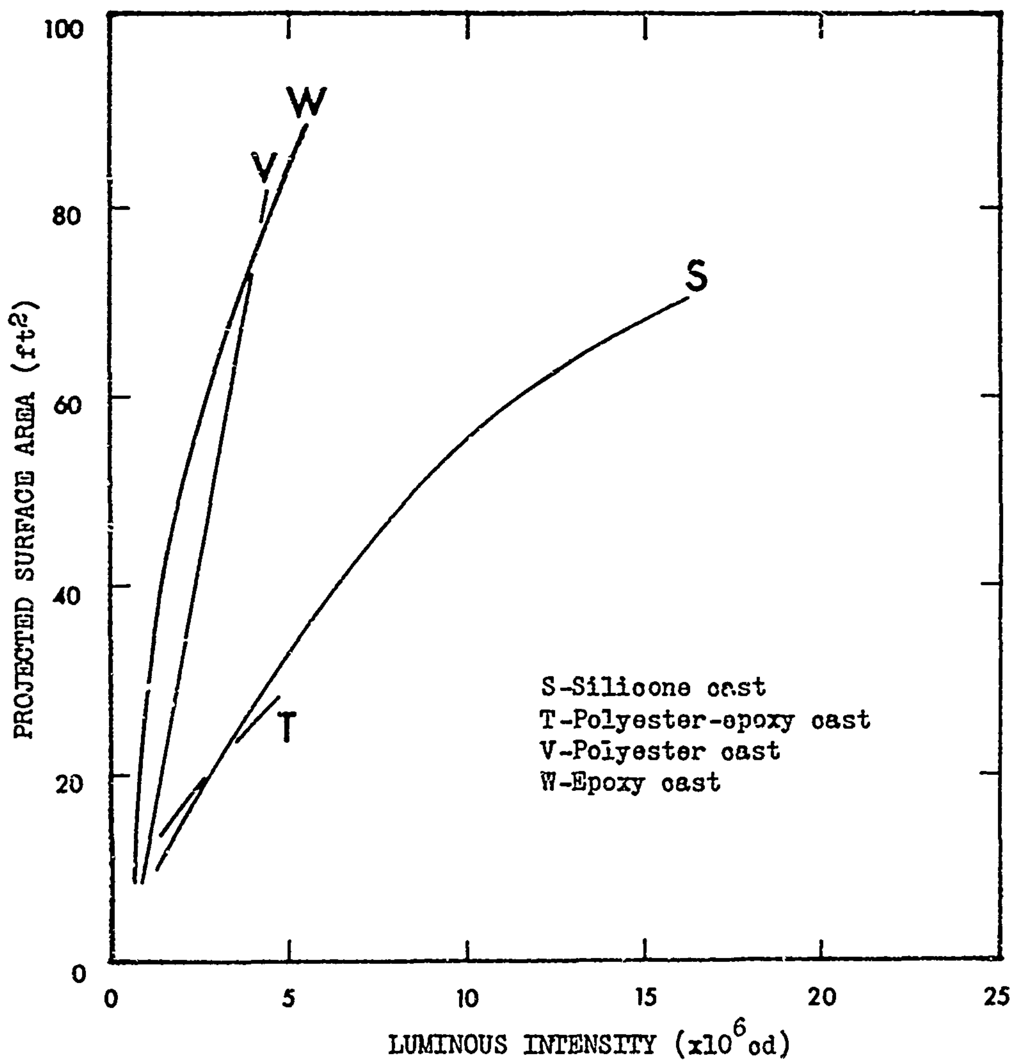

Figure 13: Effective Brightness Curves. Projected surface area of the flame vs luminous intensity for candles cast with various binder types. High luminous efficiency (silicone and polyester-epoxy) correspond to high effective flame brightness (curves S and T).

Figure 14 was prepared to show the way that the flame projected surface area varies between the epoxy (curve Y) and silicone (curve X) binders from a given candle size. Generally, from a given candle diameter, the epoxy binder generated a flame with a larger projected surface area. This observation corresponds well with the postulate advanced earlier that a small flame from a given candle diameter is associated with a high luminous efficiency.

Most of the discussion to this point involves only solid end burning candles. In contrast to these we next will discuss data from candles which have a star cavity in the center. See Part I of this report for additional details about star cavity flares.

A flame effective brightness plot had previously been presented as Figure 6. The function is linear over an extremely wide range of projected surface area and luminous intensity. The linearity is particularly remarkable when one realizes that this graph consists of both epoxy and silicone binder types used to make flares with single-star-blind-holed cavities, as well as flares with a star cavity completely through the unit. The flames from the single star units were displayed vertically and downward, whereas the flames from the double star unit were displayed horizontally opposed. Finally, the luminous intensity ranges from 5 million

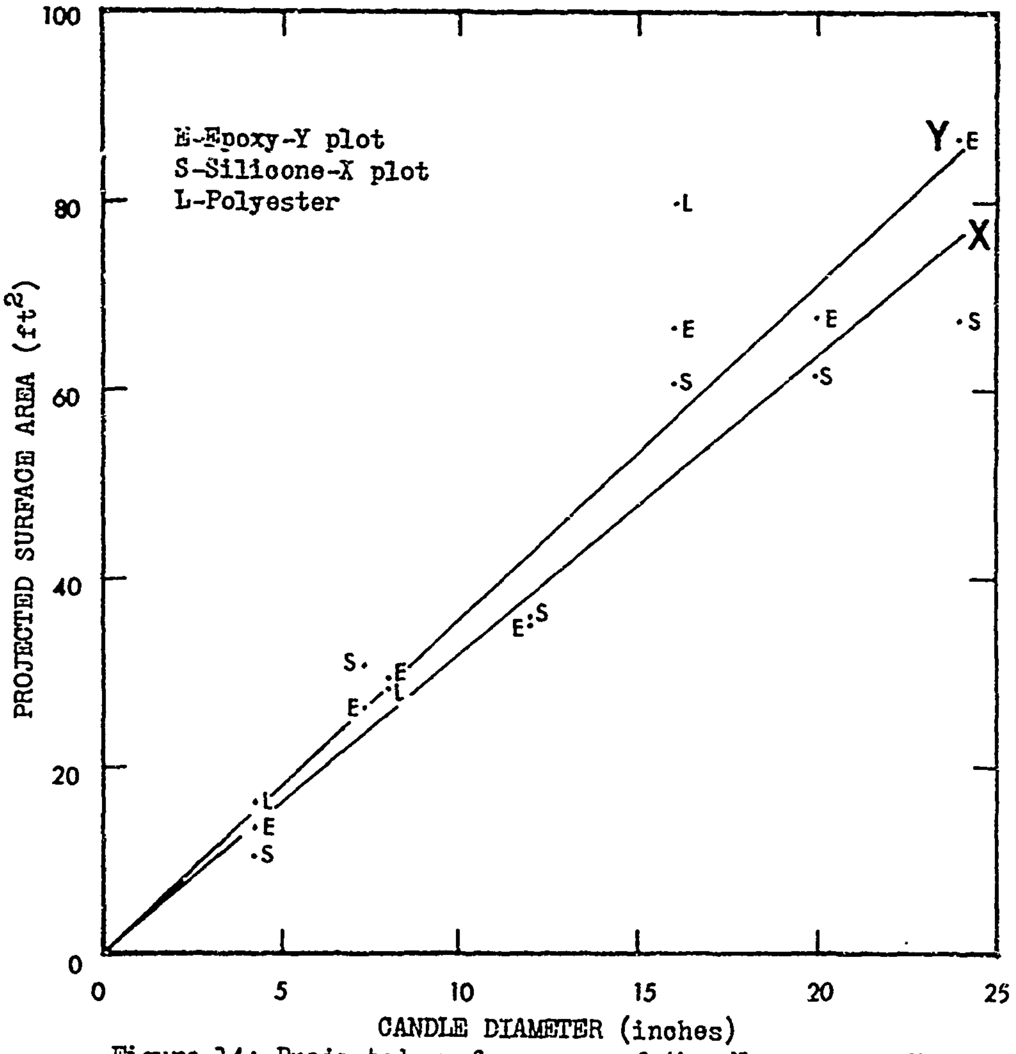

Figure 14: Projected surface area of the flame vs candle diameter for candles cast with different binder types. Shows candles with silicone binder generally have smaller flame from given size.

candles through 25 million candles. Clearly then, in this configuration the influence of the binder type seems to have been removed. The changeover from the non-linear function to one which appears to be linear may be an indication that an equilibrium condition has been achieved.

Experimental Uncertainties

As mentioned previously the values for the projected surface area of the flame are taken from movies of the flame image which has been projected by a parabolic mirror onto an easel. These values contain considerable variation due to differences in the type of film used, such as black and white versus color, variation in film development procedures, variability of the camera f-stop, smoke obscuring the flame, wind causing distortion of the flame, and the ability of the film reader to pick that frame which is representative of the entire burn, planimeter it and compare that value to the average luminous intensity for the flare. Clearly then there is ample opportunity for uncertainty in the presentation of these values.

When the program first started, the photographic data being collected was intended for use primarily to monitor the flame. When it was realized that the data being collected could be valuable for later evaluation in regard to the projected flame surface area, it was clear that some control over the methods would have to be placed in effect. From this point on, black and white film was always used, the lens opening was fixed at f5.6, and the same camera operating at 24 frames per second was used. Data plotted after these

adjustments were made seemed to form reasonable patterns. However, some of the data taken when colored film was used or when the camera lens stop was allowed to vary does not behave in a predictable manner. For example, in Figure 6 for the cast star cavity flares, candle MAPI 394 was taken with a variable f-stop and MAPI 463 was recorded on color film. Neither of these two data points fall in the region of expected behavior. In like manner in the silicone cast flare graph (curve S) of Appendix 8, candles MAPI 370, 371, 465 and 467 were recorded on color film and MAPI 393 was taken with an unknown lens opening. These data all deviate from the expected pattern. On the other hand, if these data are neglected the remaining data points form an effective brightness curve which appears reasonable.

Discussion of Flame Orientation

Another aspect of the study of flame size and shape is its orientation. In discussing the double star cavity flares (Part I), we pointed out the horizontal display of the flame from these units. The question naturally arises regarding the distribution of the light from such a flame.

In Figure 15, one can see the recorded luminous intensities at the location of each photocell. The high intensities in the 5 o'clock and 11 o'clock regions verify that the horizontally opposed flames were broadside to these regions. The flame tips were pointed toward 2 o'clock and 8 o'clock.

A particular feature of Figure 15 which is remarkable is that almost all regions directly below the flame give high intensities. This most desirable characteristic of the horizontally displayed flames is due to more efficient smoke removal from this region we can see a direct contrast to this in Figure 16 which shows the luminous intensities for each photocell for a 16-inch diameter solid cylindrical candle burned vertically with the flame pointed toward the ground. In Figure 16, the entire region directly below the flame is partially obscured by smoke as evidenced by the low intensity readings. Additional data of this nature for candles

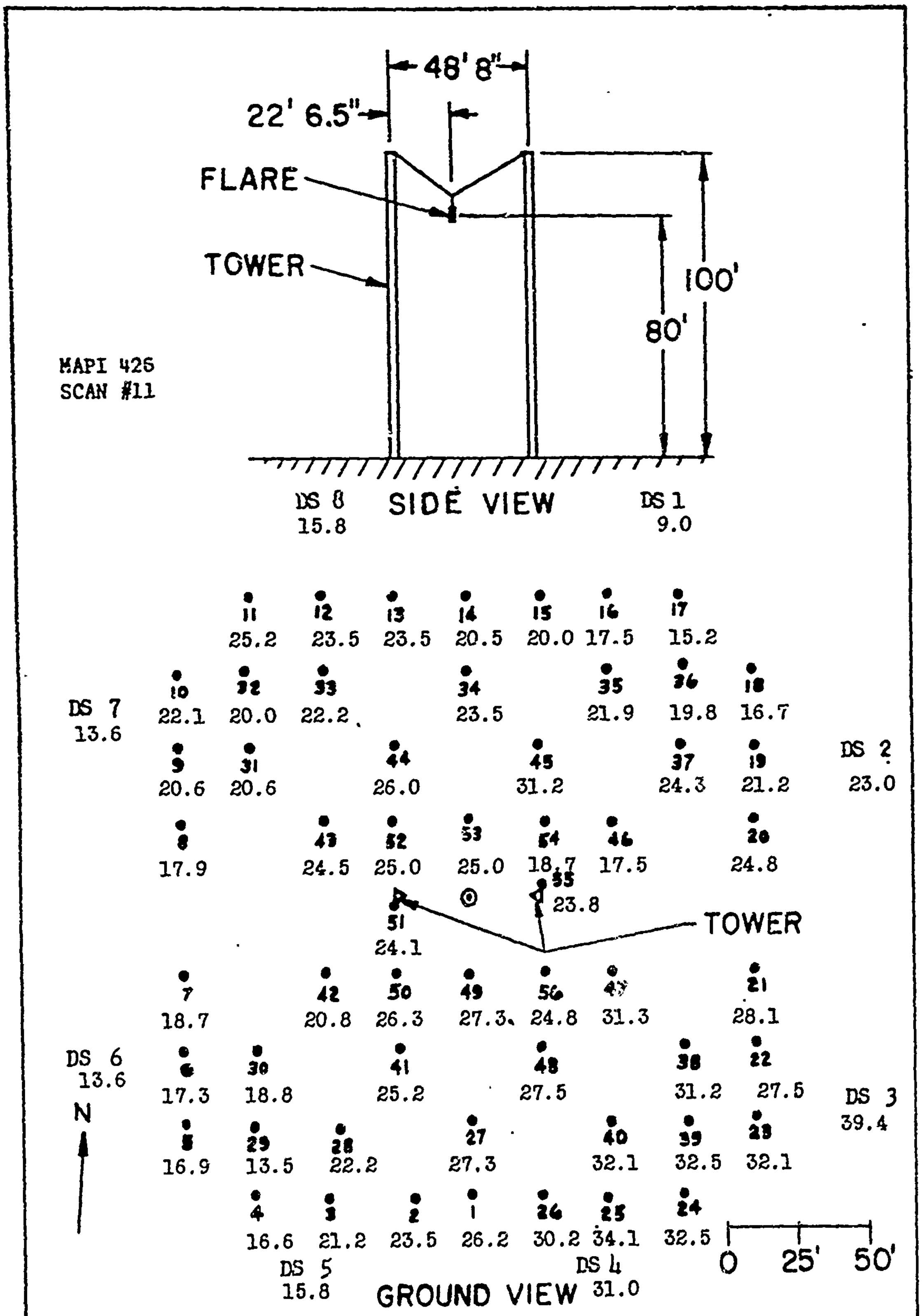

Figure 15: Luminous intensity ($\times 10^6$cd) by photocell at about 12th second into the burn of double star cavity candle MAPI 426.

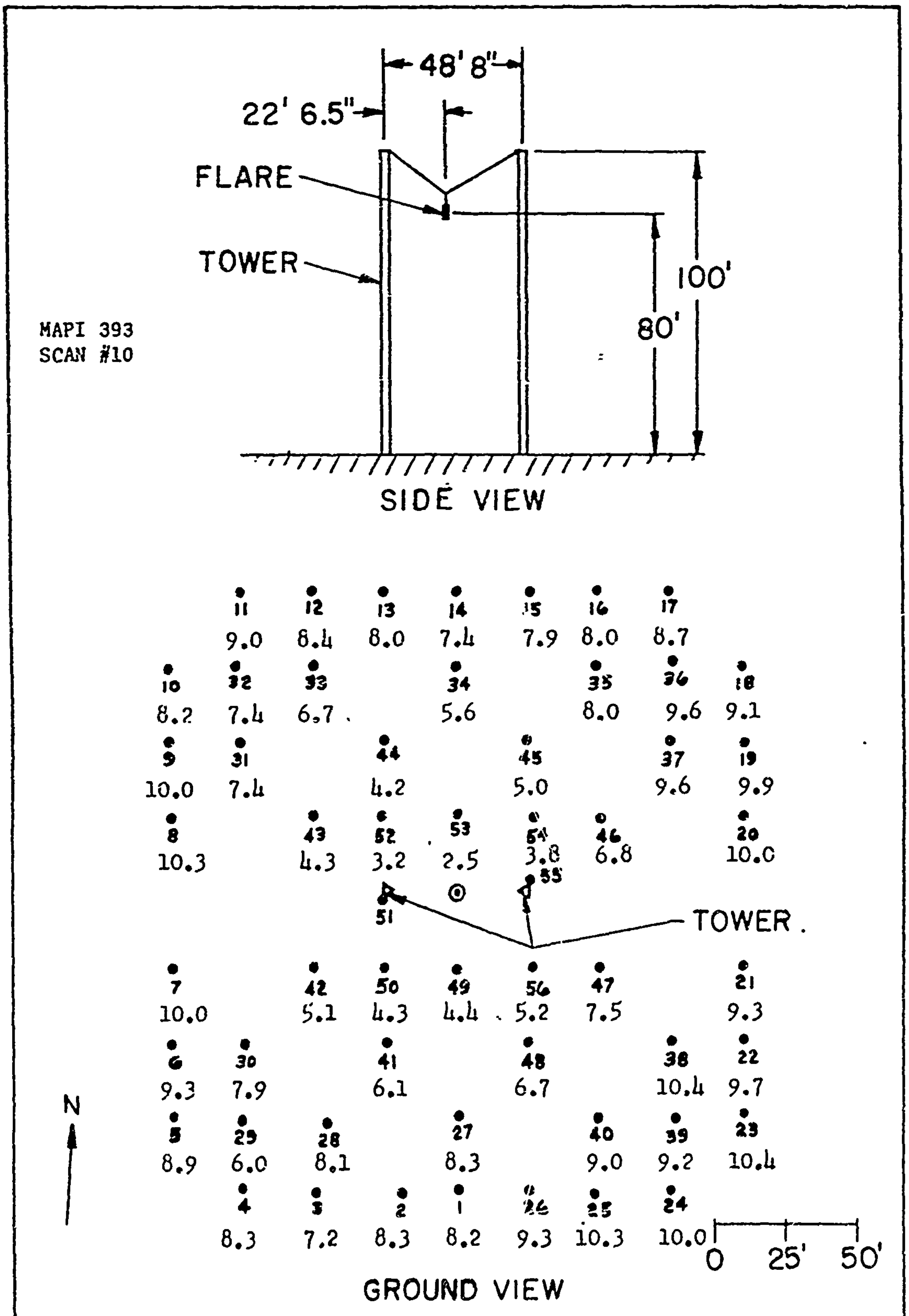

Figure 16: Luminous intensity ($\times 10^6$cd) by photocell at about 11th second into the burn of 16" diameter solid cylindrical candle MAPI 393.

MAPI 426 and 394 may be found in Appendix IX.

The flame orientation study is not complete. The limited data are presented here mainly to show the effect of smoke directly below a flame displayed vertically in contrast to the lack of smoke interference from a horizontal flame.

Conclusions

This part of the program provided several interesting results. One of the most amazing is that from a given candle diameter a small flame rather than a large flame is associated with high luminous efficiency. This observation is the exact opposite of what might have been expected. It was found also that the binder type has an overwhelming influence on the size of flame which is formed. It generally follows that the binder which produces the smallest flame is the best for making candles which radiate light with a high efficiency.

The foregoing statements apply to candles which are solid cylindrical end burning items with the flame in a vertical position and pointed toward the ground. In direct contrast to this orientation is the flame from the double star cavity candle which develops horizontally to the ground and is the result of combustion inside of a cavity. In units such as the latter the strong influence of the binder type which was present in the end burning candles seems to have been removed. This behavior points up the importance of candle shape and suggests how candle geometry can be used to transform an otherwise unacceptable binder system into a most useful one.

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13. ABSTRACT The feasibility of making an illuminating candle which produces a luminous intensity of 25 million candles is demonstrated. The goal is achieved by igniting all surfaces of a star shaped cavity which is formed through the center of the candle.

The relationship between candle diameter and the ability of that candle to generate light efficiently is reported. A general degradation of efficiency is observed as the cast candle diameter increases from 4 inches to 24 inches.

Silicone, epoxy-polyglycol, polyester, polysulfide, epoxy-polyester, sodium perchlorate-methyl methacrylate, and various combinations of these binders are described as they are used to make candles for the diameter study, the binder study, and the 25 million candle flare.

Flame orientation and flame size effects are described. Contrary to common opinion, it is shown that a small flame size rather than a large flame from a given candle diameter is associated with candles which produce light with high efficiency. The binder is shown to be a major factor in the generation of various flame sizes and thus strongly influences the candle efficiency.

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Security Classification

Security Classification

14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
Flares Illuminating Compositions Cast Flares Binder Study Epoxy Resins Methacrylates Perchlorates Sodium Nitrate Magnesium Polyester Resins						

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RDTR No. 145
March 1969

HIGH INTENSITY TAMP-CAST ILLUMINATING FLARE
(Summary Report July 67-December 68)

U. S. NAVAL AMMUNITION DEPOT
CRANE, INDIANA

45

U. S. NAVAL AMMUNITION DEPOT
CRANE, INDIANA 47522

RDTR No. 145
March 1969

HIGH INTENSITY TAMP-CAST ILLUMINATING FLARE
(Summary Report July 67-December 68)

BERNARD E. DOUDA

Prepared under MIPR PG-6-58 for the Illumination Branch, Targets and Missiles Division, Air Force Armament Laboratory, Eglin Air Force Base, Florida.

This report was reviewed for technical accuracy by Captain Gene Holder, Illumination Branch, Targets and Missiles Division, Air Force Armament Laboratory, Eglin Air Force Base, Florida.

Submitted by:

B. H. CALKINS, Manager
Concept Development Division

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ABSTRACT

The development of a high intensity tamp-cast illuminating flare is described. The flare produced a luminous intensity of 25 million candles for over two minutes. A brief discussion is included concerning the binder systems used to make the tamp-cast flares along with the assembly of a capability for testing the flares. Summary data of flare tests related to this work is included.

INTRODUCTION

The exploratory development of an illuminating flare whose luminous intensity is 25 million candles was undertaken about June 1966 under MIPR PG-6-58. The first year's progress was reported by reference (1). During the first year, it was demonstrated that a flare with a luminous intensity of 25 million candles could be built. As a result of this, the work was continued with a new goal.

The next phase of the work from July 67 to October 68 was directed toward the building of a flare which would not only provide a luminous intensity of 25 million candles but also would do this for a two minute period or more. This then is the phase of work which is reported herein.

The new goal and binder improvements which became known during this period caused the work effort to be divided into several smaller units. These are:

Part I   Build a flare with a luminous intensity of 25 million candles for two minutes

Part II   Evaluate improved binder system

Part III   Provide minimum capability for testing the flares,

Part IV   Perform flare tests relevant to this flare program.

These are the major subdivisions of the work during this period which are discussed in the text of this report.

PART I

25 MILLION CANDLE FLARE

Purpose

The purpose of this report is to describe the development effort which led to the fabrication of an illuminating flare candle which generates a luminous intensity of 25 million candles for two minutes or more.

Background and Review

In order to orient the reader it is useful to include some of the background which leads to the concept of tamp-casting and to review the progress of the work prior to the start of this report period. With this in mind, we can start with a review of the state-of-the-art of flare pressing.

During the manufacture of a conventional illuminating flare, the composition is normally consolidated into the flare container at a pressure near ten thousand psi. Furthermore, when it is necessary to make flares with a large cross-sectional area, extremely large presses are required in order to achieve the 10,000 psi consolidation force. Thus, the size of the candle that can be made is often limited by the size of press which is available. For example, a press of about 200 tons is required to consolidate the composition into an 8-inch diameter flare. Larger flares would require correspondingly larger presses.

Since the consolidation operation becomes more complex as the size of the equipment increases, it becomes increasingly attractive from an economical standpoint to eliminate the consolidation operation. This can be achieved if the composition can be "cast" into the candle container instead of pressed. The tamp-casting method is the technique chosen to make candles in this program. Generally, the composition will not flow and therefore is tamped at pressures near 50 psi. For purposes of this report, the process of tamping and later polymerization of the composition is what is known as tamp-casting a flare candle.

In an effort to attain outputs of 25 million candles, flares were first made in the normal solid cylindrical shape. It was estimated that flares of sufficient diameter and size could be made which would provide the required 25 million candle output. Prototypes of such flares were tested. They were burned in cigarette fashion. Two important characteristics of the experiment became evident: First, the luminous intensity output was found to degrade as the diameter of the candle increased. At the start of this program this degradation function was not defined. Further discussion may be found in reference (1). The other benefit that came from this phase of the work was the development of the techniques required to process the composition. During the manufacture of the solid candles, various mixing, tamping, and casting techniques

were tried. In addition, different composition formulas were used. All of this led to the preparation of candles which were suitable for performance testing.

During the early phases it was learned that it was necessary to burn about five pounds of composition per second in order to generate luminous intensities of 25 million candles. This in turn requires the burning of large composition surface areas in order to obtain the desired output. Since this would require candles of extremely large diameters if they were made as a solid cylinder, another approach was taken. Candles were made which had a star-shaped cavity in the center of the grain. The purpose of the star cavity was to present a larger surface area for burning. This idea is based on computations developed for the burning of propellant grains of various star configurations.

Candles were made with a star-shaped cavity completely through the center of the candle. When the candle is ignited, the flame exits from both ends of the candle. This produces equal but opposing forces thereby eliminating any major propulsion effect. It was also decided to suspend the candle in a horizontal position which causes the flames to develop horizontal to the surface of the ground. In this manner, a larger projected cross-sectional surface area of the flame is presented to the ground surface.

This double star candle design was used successfully to generate the required luminous intensity of 25 million candles.

All of the candles prepared the first year were tested at the MAPI site. In general, the MAPI site may be described as a polar arrangement of about 56 photocells on the ground each of which views the candle suspended about 80 feet in the air. The cells are arranged such that the flare is viewed from all aspects. Eight cells were added to the MAPI system during the latter part of this phase. The cells were placed at greater distances from the flare in order that the entire flame could be viewed by the cells. Additional details about the MAPI site may be found in references (1), (2), (3), (4) and (5).

The 25 million candle output requirement was first demonstrated by both candles MAPI No. 426 and MAPI No. 463. In each case, about five pounds per second of composition is burned. Also, the computations show that efficiencies in (cd-sec)/g generally range from ten to twelve thousand. See Table II, page 14 of Volume I to reference (1). This is only about one-fourth of the efficiency achieved when compared to the standard pressed illuminating composition in a four-inch size. Although these efficiencies are low, it was shown in the next year's work that they could be improved considerably by utilizing more efficient binder systems.

Two different binder systems were utilized to make the double star candles. We noticed that the silicon resin system has the

characteristic of burning much faster than did the epoxy-polyglycol system for comparable composition formulas. See references (10), (11) and (12) for more information about these binders. Both of these resin systems have the very desirable characteristic of a very low exotherm during the polymerization reaction. Generally, their pot life is about eight hours which permits adequate time for the casting process. After the candle is cast, it is placed in an oven at around 150-170°F for 24 hours or more to cause the cure. During this curing period, the exotherm is almost unnoticeable. This characteristic is extremely important from a safety standpoint, in particular when it is necessary to cure large section candles. Because the exotherm is low, there is less danger of exceeding the decomposition temperature of any of the flare ingredients.

The first phase proved that a luminous intensity of 25 million candles could be generated by a pyrotechnic illuminating flare. Furthermore, the information gathered during this phase of the program indicated that considerable improvement could be made by increasing the efficiency of this system. From this start, the effort progressed toward the goal of a two minute flare producing a luminous intensity of 25 million candles and a higher efficiency composition.

Experimental

By the end of the first year it had been demonstrated that from a single source it is possible to produce a luminous intensity of 25 million candles. From this data it was apparent that a two minute burning time candle could be made provided the diameter of the candle was about 20 inches. From other information available, it was estimated that such a candle would weigh in the neighborhood of 500 pounds. This weight was more than the original test facility could tolerate. Secondly, the flames from these candles extend to about 15 feet on either side of the candle while burning at peak intensity. The photocells viewing this flame must see the entire flame if reliable data is to be obtained. Also, all the intensity computations are based on the premise that the source is a point source. Certainly a photocell at a distance of eighty feet from a 20-30 foot long flame can not be considered to be viewing a point source. For this reason and that of the weight limitation, it was necessary to provide a test facility with a larger capability. That effort will be discussed Part III.

While the improved test site was being prepared, further tests were planned. These mainly involved the adjustment of the formulas as well as the evaluation of an improved binder system which recently had become available as reported in reference (6). This improved

system is also described in Part II of this report. To perform these tests and still stay within the weight limitations, candles were made in a twelve-inch diameter size. These small test samples were used to establish the burning rate for a given composition. That information was used to scale up into a larger version the latter of which to be tested on the improved test site when that became available.

The summary sheet, Table I, on the next page compares data for a series of candles which were prepared during the intervening six to eight months. MAPI 659 and 665 show two flares each with a different binder. One flare had an efficiency of about 12,000 cd-sec/gm and the other about 10,000 cd-sec/gm. Had we not learned about the improved epoxy-polyester system about this time we probably would have conducted further tests on the MAPI 659 formula which in turn eventually would have been scaled up. Since however the improved resin system was showing great promise, tests were immediately conducted to determine its usefulness in the double star cast flare system. After it was determined that the material could be processed, flares MAPI 706 and 709 were made from this material. Additional details about the flare fabrication process can be found in Appendix I, Volume II of reference (1). More information about these candles is also included in the Table I.

TABLE I

12.0" DIAMETER DOUBLE-STAR CAST FLARES

19 February 1969

MAPI Test No.	657	658	659**	665	706	709	B1
Magnesium %	36	55	53	56	57	57	57.5
(granulation)	18	15	17	17	17	17	17
Sodium Nitrate %	50.0	31	33	30	30.5	30.5	30.5
(particle size)	150 μ	150 μ	150 μ	***	***	30μ	30μ
Binder* %							
Silicone	14	--	--	14	--	--	--
Epoxy-Polyglycol	--	14	14	--	--	--	--
Epoxy-Polyester	--	--	--	--	12.5	12.5	12.0
Luminous Intensity ($x10^6$cd)	4.0	17.5	10.0	14.4	>22.5	24.7	~25
Burning Time (sec)	128	45	75	51	71	73	138
Efficiency ($x10^3$ cd-sec/g)	4.8	8.0	12.0	10.0	21.7	22.4	~15
Burning Rate (in/sec)	0.02	0.06	0.04	0.05	0.04	0.04	0.05
Burning Rate (sec/in)	42.6	15	25	17	23.6	24.3	19.7
Burning Rate ($x10^3$g/sec)	0.85	2.1	0.84	1.44	1.04	1.10	1.80
Density (g/cm^3)				1.44	1.42	1.57	1.41
Composition Weight ($x10^3$g)	108.9	97.6	62.6	73.6	73.6	80.5	234
(lbs)	240	215	138	162	162	177	516
Composition Length (in)	42.1	44.2	26.2	29.8	30.5	30.3	33.4 ****

* Silicone formula: Sylgard 182 mix.
Epoxy-Polyglycol formula: 62% QX 3812 and 38% DER 732.
Epoxy-Polyester formula: 81.89% Foamrez F-17-80, 17.0% ERL-0510, and 1.11% Iron Linoleate.

**Denotes 6-point star; all others are 4-point stars.

***50% 30 micron and 50% 150 micron.

**** This unit is 20 inches diameter.

The most important performance characteristics resulting from the tests of MAPI 706 and 709 was the fact that in each case the luminous intensity was near the required 25 million. Both units showed a luminous efficiency of about 22,000 cd-sec/gm which is almost double what had been accomplished previously with other binders. This bonus performance was one which would later make the goal much easier to meet. From this point, the scale-up proceeded.

Based on the successful test of candles MAPI 706 and 709, a twenty-inch diameter candle MAPI B1 was made using the epoxy-polyester binder system and the formula shown in Table I. The test of that candle showed that the unit produced an average luminous intensity of 25 million candles for a period of 138 seconds. Thus the goal of this phase had been met.

The flare MAPI B1 was not what one might consider to be a perfect candle. It did not burn as smoothly as had been desired. As a matter of fact, at about 45 seconds into the burn, the flare started to discharge chunks of composition while burning. This suggested that there might be cracks in the composition or there might be an inadequate bond between the composition and the case. From later investigations, it appears that the latter was the condition that existed. Some of these problems will be discussed in Part II of this report. This partial chunking of the

composition from the candle while burning undoubtedly accounted for the reduced efficiency (15,000 cd-sec/gm) recorded for this unit. Even in the light of the reduced efficiency, however, the unit did meet the minimum requirements of the test.

Figure 1 shows a plot of luminous intensity as a function of burning time for Flare MAPI 709. It is easy to see that it is nearly 30 seconds before the unit reaches the required 25 million candles intensity. It should be noted that this unit contained a star cavity which had four points. Previous experiments with these flares have shown that a peak intensity can be reached more quickly if certain changes are made. The time to peak intensity can be increased by using a faster burning composition which sometimes can be achieved by utilizing a finer granulation of magnesium. Another means of achieving a faster time to peak is to start with a six point star cavity instead of a four point star. For further information about the behavior of the star cavities, the reader is referred to Appendix II of Volume II of reference (1).

Either of these techniques can be used independently of the other or, if one chooses, both can be incorporated into one candle. When the latter is used, the time to peak will be extremely fast. It had been considered during this program that such a modification might be utilized to advantage. If this had been

FIGURE 1

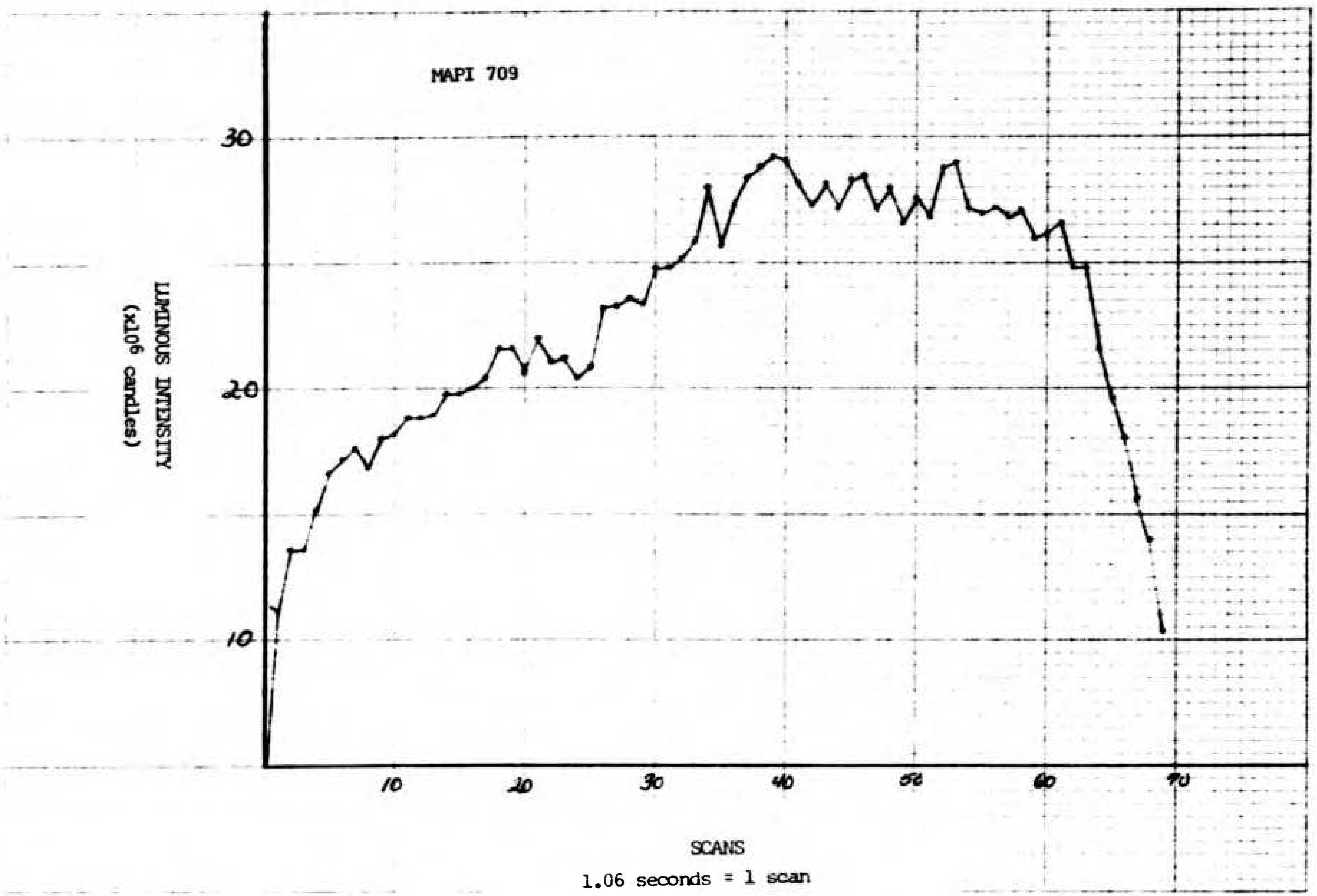


FIGURE 1

done, the flare would probably start out with a very high intensity which would gradually taper to a lower intensity. For example it might start out averaging near 30 million and taper to an average of 20 million as the burn progressed. Such a characteristic might be used to advantage since the high intensity portion of the burn would probably correspond to initiation of the flare at high altitude. As the flare drops in altitude there would also be a decrease in luminous intensity; the net result of which would be constant illumination on the ground. Such a condition is considered to be advantageous from a tactical standpoint.

Conclusion

During this phase it was demonstrated that a luminous intensity of 25 million candles can be delivered by a single pyrotechnic illuminating flare over a period of more than two minutes. An improved binder system was utilized to prepare this flare. MAPI B1, which weighed 516 pounds was tested on the improved MAPI site. This test not only proved that the flame met the minimum requirements set for the program but it also proved the versatility and acceptability of the improved test facility.

PART II

BINDER STUDY

Purpose

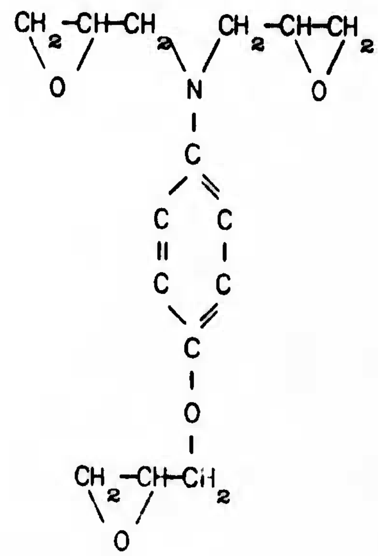
The object of this phase of the project was to determine the usefulness of an epoxy-polyester binder system for making the star-cavity tamp-cast candles.

Discussion

It has already been mentioned in PART I that during the program a seemingly improved binder system was being evaluated in flare systems. References (1) and (6) contain data about the early applications of this material. Because of the promise that the material showed in other areas, it was tried in this program as well. The results of this effort are described herein.

The formula for the epoxy-polyester system used to tamp-cast the double star cavity candles, consists of about 81.89% Formrez F17-80 polyester resin, 17.0% ERL-0510 epoxy resin, and 1.11% iron linoleate. See reference (7) for information about the use of these materials for pressing flares.

The epoxy resins ERLD-0500 and ERL-0510 are both products of Union Carbide Corporation manufactured under U.S. Patent 2,951,825. The idealized structure is:



The two products are triglycidyl derivaties of para-amino phenol. ERLD-0500 is the reaction product of para-amino phenol and epichlorohydrin in the presence of caustic. Like all such products, ERLD-0500 contains some polymeric material with pendant hydroxyl groups. Commercially produced, ERLD-0500 has a viscosity of 2000 to 5000 cP* at room temperature. The presence of hydroxyl groups in the material produces some catalytic effects and hence shortens potlife. To overcome this, the ERLD-0500 is molecularily distilled to produce a product known as ERL-0510 which is essentially the monomeric triglicidyl derivative of para-amino phenol.

It is a pale straw-colored liquid with a viscosity of 400 to 700 cP*.

*From Union Carbide Product Data sheets. cP = centipoise.

Formrez F17-80 is a carboxyl terminated polyester produced by Witco Chemical Company. Its emperical formulation and typical analysis is:

Emperical Formulation

$C_{1.6}\ H_{2.55}\ O_{1.0}$

Typical Analysis

Hydroxyl, No.	3.0
Acid No. **	72.0
Moisture, %	0.04
Viscosity, cP @ 25°C	40,000

**milligrams KOH per gram of sample

Source data and information about the remaining ingredients such as magnesium, sodium nitrate, and iron linoleate may be found in Table II.

No difficulties were experienced in using this binder system in early applications. The resins were first tried in small solid cylindrical candles made by a tamp-cast method. After the small units showed acceptable performance, MAPI candles 706 and 709 were made. The latter two candles are the first units containing a star cavity which were made with the improved epoxy-polyester resin system. Although no difficulties were noticed at the time, the problems which were later to arise quite

TABLE II

List of Materials

Formrez F17-80 Carboxyl terminated polyester resin	Witco Chemical Co. 75 E. Walker Drive Chicago, Illinois 60601 Phone: 312-346-2960
Epoxy Resin ERL-0510 Thiokol Chemical Corp. Specification TWS-RM-1003	Union Carbide Corp. 230 North Michigan Ave. Chicago, Illinois 60601 Phone: 312-346-3300
Epoxy Resin ERLD-0500 Thiokol Chemical Corp. Specification TWS-RM-64	Union Carbide Corp. Plastics Division 2330 Victory Parkway Cincinnati, Ohio 45206 Phone: 513-272-0202
Iron Linoleate Thiokol Chemical Corp Specification TWS-RM-1002	Harshaw Chemical Co. 1945 East 97th St. Cleveland, Ohio 44106 Phone: 216-721-8300
Sodium Nitrate	Davies Nitrate Co. P.O. Box 306 Metuchen, N.J. 08840
Magnesium Atomized grades	Valley Metallurgical Processing Co. Essex, Connecticut 06426

prominently may have been present but in a reduced form. In any event, as pointed out in Part I, MAPI 706 and 709 performed satisfactorily.

When this work was completed, MAPI B1 Candle was made. This 20 inch diameter unit was a direct scale-up of MAPI 706 and 709. It was here that potlife problems were first experienced. That is, the material had a tendency to set up while in the mixer (15-30 minutes) as compared to what previously had been a four hour potlife at ambient temperature.

Originally there did not seem to be any correlation between the behavior of the composition used to make MAPI 706 and 709 and that used to make MAPI B1. It had however been noted that, the first units were made during the Winter period (relatively low humidity) as compared to MAPI B1 which was made during the Spring of the year (high humidity). Although this feature may have played a role in the difficulties which were experienced, it does not seem to be the sole source of the main problem.

Another change was noticed between MAPI 706, 709 and MAPI B1. The first two units were made with a magnesium from a different shipment than was used to make the third unit. Although the granular size in all three units was the same and the material was from the same manufacturer, it now appears to be very likely that the magnesium in the two shipments had surface conditions which made them different in some way.

About this time it was learned that the Thiokol Chemical Corporation was also having similar difficulties to that just described. Mainly the difficulty shows up in an extremely short potlife. The problem then becomes one of finding out the source of this short potlife. After discussion with representatives of the Thiokol Chemical Corporation and with manufacturers of the individual ingredients and resins it appears that the problem may generally be described as follows:

The Formrez F17-80 is reported to have an acid number of 72. In this material there apparently is residual succinic anhydride which is used in the process of manufacturing the resin. When moisture is allowed to come into the presence of the anhydride, that material converts to succinic acid. The acid is then available to react with the magnesium which in turn causes gassing and a catalysis of the polymerization reaction. At this point the reader should not conclude that moisture is the only source of the problem. It is suggested that the problem may also exist in the absence of moisture for the reasons that will soon become apparent.

It was also learned through experience that the problem is aggravated when magnesium of very small particle size is used as compared to the coarser materials. This observation suggests that the problem is associated with the condition of

the magnesium surface or with its surface area. The other observation which was made concerning magnesium is that magnesium formed into a ball by a milling process is less reactive than magnesium manufactured by the process of atomization. This relationship seems to hold for a given particle size of magnesium. Once again, this suggests that the surface condition of the magnesium is relatable to the potlife problem.

During the investigations conducted into this problem, several persons had hypothesized that the magnesium oxide surface coating on the magnesium was the cause of the shortened potlife because magnesium oxide is a known catalyst for the polymerization reaction. The presence of varying quantities of oxide coating on the magnesium would explain the differences between the magnesiums prepared by the two different processes as well as the observation that fine magnesium is more reactive than is coarse magnesium. The latter results from a higher surface area which in turn would correspond to a greater amount of available magnesium oxide. If this is the case, the problem becomes one of eliminating the magnesium oxide surface condition, controlling it, or avoiding it completely.

Several methods have been suggested. Chemical neutralizers or agents that would block the activity of the magnesium oxide were suggested as additives to the resin. Another suggestion

is to avoid the use of atomized magnesium in favor of the seemingly less reactive material which had been formed into a ball by milling. Another suggestion involves treatment of the magnesium to remove the oxide coating. All of these techniques may be successful in varying degrees. What the ultimate answer turns out to be will undoubtedly depend on the circumstances surrounding the processing and manufacturing of the item involved. These problems were not pursued further in this program because at the time that the problem came to light, the major goal of the program had been reached. Consequently, the problem was not pursued to its solution.

Conclusions

During this phase it was demonstrated that an improved polyester-epoxy resin system could be used successfully for tamp casting large star cavity flare candles. The processing procedures brought to light several problems that are associated with the use of this material. Only partial solutions have been found for this problem, although the problem itself seems to have been identified. The major conclusions reached from this phase is that flares made with this binder system have a better efficiency than those made with the binder systems tested earlier and that if the system is to be continued in this use, the means must be found to control the process to the extent that premature polymerization of the composition no longer occurs.

PART III

TEST CAPABILITY

Purpose

The purpose of this part of the report is to describe the test capability that was assembled to support this flare program.

Introduction

It has been mentioned previously in Part I that the original test facility was not capable of suspending the candle weights which would have to be tested. Secondly, it was learned that the flames from the candles being prepared in this program extend to about 15 feet on either side of the candle while burning at peak intensity. It is also clear that the photocells viewing this flame must see the entire flame if reliable data is to be obtained. It is also important to notice that all of the intensity computations are based on the assumption that the radiator is a point source. Certainly a photocell at a distance of 80 feet from a 20 to 30 foot long flame cannot be considered to be viewing a point source. For this reason and that of the weight limitation, it was deemed necessary to provide a test facility with a larger capability. Such a capability was assembled during this program.

Discussion

The site for the new capability was chosen adjacent to an existing pyrotechnic test area and within sight of the old MAPI test area. Eleven acres of land were cleared in the center of which two 300 foot towers were installed at a distance of 300 feet apart. Sixteen photocells were scattered over the eleven acres in an array varying in distance between 100 feet to 400 feet from ground zero. All of these cells view a region between the towers at about 250 feet in the air where the test unit is normally suspended. The towers have the strength necessary to suspend weights up to 2500 pounds for significant periods of time. See Figure 2 for the site layout. Figure 3 is aerial view.

The details of the electronics of this improved capability as well as the sensing head calibration are given in reference (8). Generally, the procedure is as follows: During a time span of about one second, all of the sixteen photocells are sequencially sampled one time. The intensity of each of the sensing heads at the time it is sampled is recorded on magnetic tape. That information, along with calibration data, information concerning the sensing heads, and the geometric location in relation to the test unit is converted to digital form for analysis by computer. Such a procedure permits the computation of luminous intensity for each

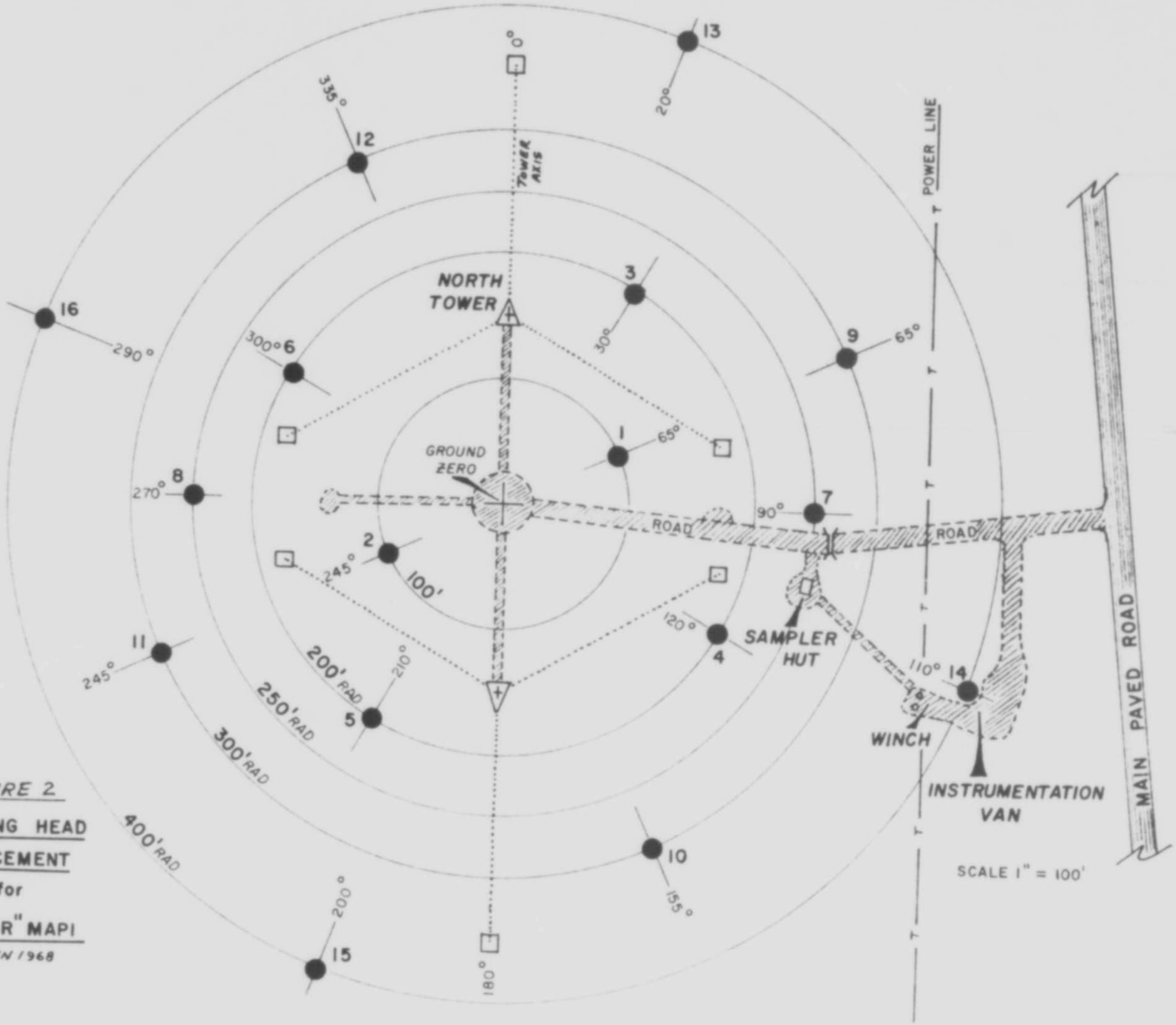


FIGURE 2

SENSING HEAD PLACEMENT for "SUPER" MAPI

3 JUN 1968

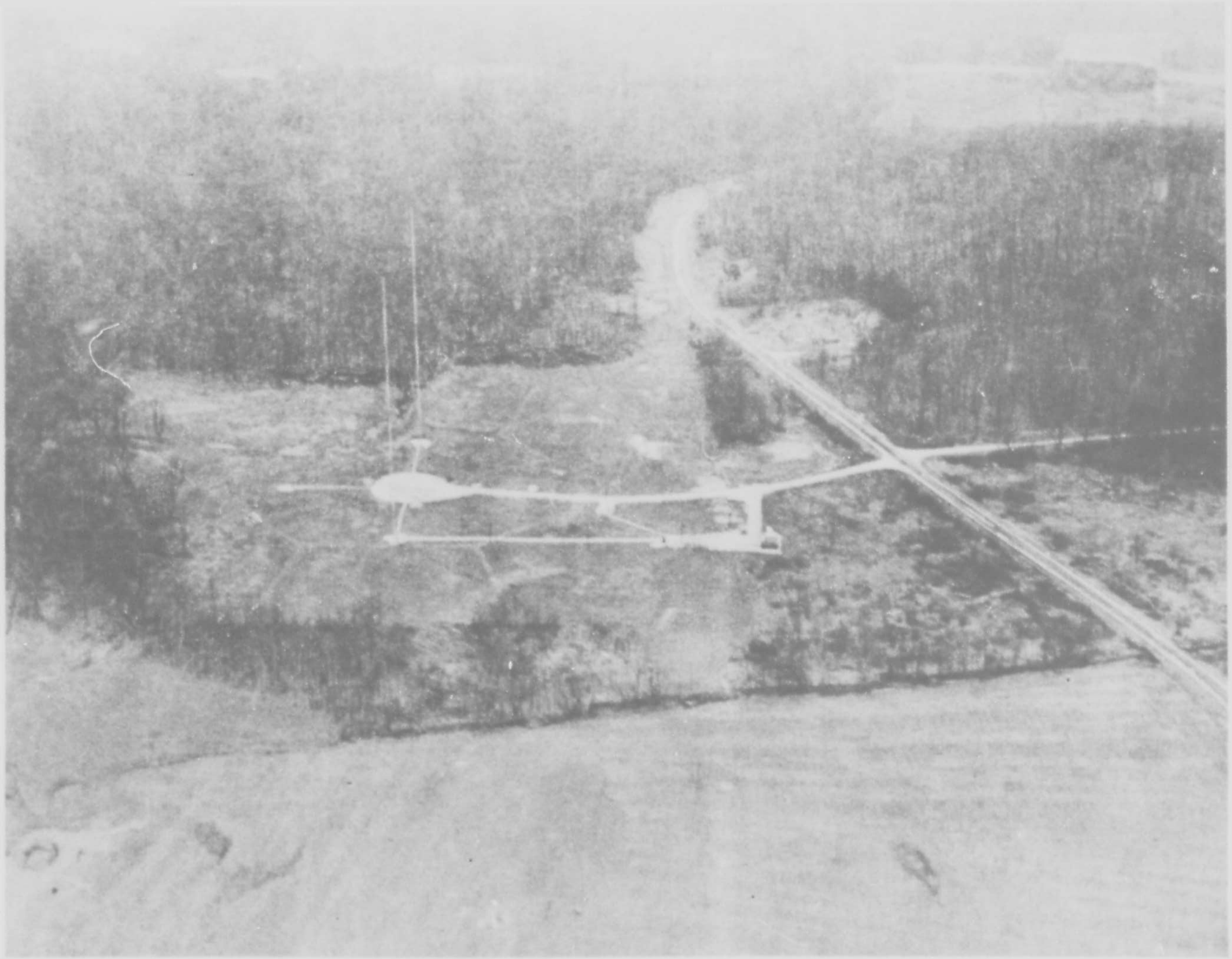


FIGURE 3

Aerial view of "SUPER" MAPI

sensing head during each second of burning time. With this information one can assess the directional performance of the unit. For example: intensities directly below the flare may be compared to some other region of the test site. Additionally one is able to assess the degree to which the smoke generated by the unit interferes with the ground illumination in any region of the test site.

Conclusions

The improved test capability which later became known as the "Super-MAPI Area" has been utilized successfully for the test of flares. The site is operational.

PART IV

RELATED FLARE TESTS

Purpose

Four major tests were performed which are directly related to the work described in this report. The summarized results of those tests are included.

First Test

Twelve short Briteye Flares designated as the MLU-44/B made by the Bermite Powder Company were tested on the regular MAPI site. It should be emphasized that the units were damaged in various ways. Therefore, optimum performance was not expected. The results do, however, show what efficiency level can be expected. Table III is the summarized data.

TABLE III

MLU 44/B BRITEYE FLARES MADE BY BERMITE

MAPI Test 1 December 67

Data from SCC-650 Computer 1/6/69

MAPI #	Burning (1) Time (sec)	Luminous Intensity ($x10^6$ candles)	Luminous Efficiency (cd.sec)/g
676	177	4.23	33,600
677	185	4.10	34,700
678	192	4.42	37,900
679	13	3.55	
680	133	4.77	29,000
681	166	4.68	34,900
682	73	5.15	
683	176	4.64	36,600
684	190	4.46	37,900
685	182	4.24	34,700
686	156	4.92	34,300
687	163	4.51	33,000

(1) The burning time is the period between the time when the unit reaches 750,000 candles at the start of the burn and the time when the unit first drops below 750,000 candles at the end of the burn. The first 10 seconds of the burn are not used to compute the luminous intensity.

Second Test, LUU-3/B

Twenty-four cast LUU-3/B flares made by the Thiokol Chemical Corporation (TCC) were received for test on the regular MAPI site. Twenty-two of the units were included in this test. The remaining two flares were held for the third test (26 April). All of these flares were made for the U.S. Air Force Armament Laboratory, Eglin Air Force Base by TCC under a development contract. The flares had been subjected to a variety of environmental, durability, and safety tests prior to this test. A matter to be considered in comparing the pressed Briteye MLU-44/B to the tamp-cast LUU-3/B is that the LUU-3/B is cast into an aluminum case and the MLU-44/B is pressed into a non-metal case. This is known to account for some of the performance differences. The details of the TCC work in developing these flares may be found in reference (9). Table IV is a summary of the MAPI test data.

TABLE IV

LUU-3/B FLARE TEST
MAPI Test 29 March 68
Data from SCC-650 Computer 11/20/68

MAPI # (1)	Burning (2) Time (sec)	Luminous Intensity ($x10^6$ candles)	Luminous Efficiency (cd-sec/g)
718	281	3.99	33,400
719	285	3.92	33,300
720	371	2.97	37,300
721	380	2.60	32,600
722	recorder failure		
723	364	2.56	31,400
724	360	3.22	39,200
725	225	5.19	38,600
726	336	3.62	40,100
727	330	3.82	41,700
728	316	3.90	40,800
729	303	3.93	39,800
730	307	3.20	33,300
732	279	4.66	45,900
734	293	4.38	45,000
735	340	3.80	43,000
736	334	3.94	44,300
737	280	4.47	44,500
738	305	4.27	45,100
739	317	3.96	42,700
741	286	4.85	41,300
742	297	4.31	45,200
743	294	4.87	50,600
744	267	4.63	43,700
745	312	4.27	45,600
746	252	4.90	36,800

(1) #718, 719, 741 and 746 are pressed MLU-44/B flares made by NAD Crane. The remainder are cast MLU-44/B flares made by Thiokol Chemical Corporation.

(2) The burning time is the period between the time when the unit reaches 750,000 candles at the start of the burn and the time when the unit first drops below 750,000 candles at the end of the burn. The first 10 seconds of the burn are not used to compute the luminous intensity.

Third Test, LUU-3/B

Two LUU-3/B flares were held out from the 29 March series. This was done to get a second comparison of the LUU-3/B to the pressed standard Briteye. These two units along with six Briteye Flares were tested on 26 April 1968 after recalibration of the MAPI instrumentation. Generally, the trends indicated by the second test were repeated. Table V is a summary of that data.

TABLE V

LUU-3/B FLARE TEST
MAPI Test 26 April 1968
Data from SCC-650 Computer May 1969

MAPI (1) Number	Burning (2) Time (sec)	Luminous Intensity ($x10^6$ candles)	Luminous Efficiency (cd-sec/gm)
671	282	4.99	39,000
672	278	4.71	37,000
673	280	4.82	38,100
674	289	4.54	44,500
675	308	4.38	38,100
676	recorder failure		
677	311	4.26	45,100
678	307	4.42	38,300

(1) #671, 672, 673, 675, 676, and 678 are pressed MLU-44/B flares made by NAD Crane. #674 and 677 are cast LUU-3/B flares made by Thiokol Chemical Corporation.

(2) The burning time is the period between the time when the unit reaches 750,000 candles at the start of the burn and the time when the unit first drops below 750,000 candles at the end of the burn. The first 10 seconds of the burn are not used to compute the luminous intensity.

Fourth Test, LUU-2/B

Five 4.5 inch diameter LUU-2/B flares made by the Thiokol Chemical Corporation (TCC) under contract to the Air Force Armament Laboratory were tested in the Photometric Tunnel. These units, like the 8 inch diameter LUU-3/B, were cast into an aluminum case. For purposes of comparison, the LUU-2/B flares were tested along with paper cased MK 45 production line flares and MK 45 size pressed "special" experimental flares. Reference (6) is a report of the early development of the LUU-2/B. Table VI is a summary of the test results.

TABLE VI

LUU-2/B TEST RESULTS

Test Date 22 Nov 68 in Photometric Tunnel

Item	Luminous Intensity (10^6 candles)	Burning Time (seconds)	Weight (grams)	Efficiency (cd.sec/gm)
1 Special	1.83	204	6800	55,200
2 Special	1.87	204	6800	56,100
3 Special	1.58	265	7704	54,500
4 Production	1.69	234	7641	51,200
5 LUU-2/B	1.55	279	9158	47,200
6 Special	1.56	272	7699	51,700
7 Production	1.79	217	7645	50,900
8 LUU-2/B	1.50	277	9221	45,300
9 Special	1.51	263	7708	51,800
10 Production	1.50	214	7627	42,400
11 LUU-2/B	1.48	281	9131	45,500
12 Special	1.58	253	7663	52,500
13 Production	1.62	240	7645	51,000
14 LUU-2/B	1.58	275	9158	47,700
15 Special	1.59	259	7672	53,700
16 Production	1.77	228	7604	53,100
17 LUU-2/B	1.56	275	9140	47,100

	Candles Average	Time Average	Efficiency Average
Special X (1,2)	1.85	205	55,700
Special (3,6,9,12,15)	1.54	262	52,900
Production (4,7,10,13,16)	1.68	226	49,700
LUU-2/B (5,8,11,14,17)	1.53	277	46,600

Conclusions

These data show that the tamp-cast flares, both 5" and 8", are relatively efficient as light producers. There data along with other information related to these test flares were submitted to the Air Force Armament Laboratory.

Note added in proof: See reference 13 by Northrop Carolina, Inc. concerning pressed and cast systems in a candle about 2.5 inch diameter and 11 inches long. See reference 14 by Thiokol Chemical Corporation concerning the development of an 8 inch cast flare.

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The Denver Research Institute, University of Denver assisted in much of the improvement of the Super MAPI site under Contract to NAD Crane. Without their cooperation, and especially that of Mr. R. M. Blunt, Research Physicist, the assembly of the improved capability would have been extremely difficult.

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The development of a high intensity tamp-cast illuminating flare is described. The flare produced a luminous intensity of 25 million candles for over two minutes. A brief discussion is included concerning the binder systems used to make the tamp-cast flares along with the assembly of a capability for testing the flares. Summary data of flare tests related to this work is included.

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	ROLE	WT	ROLE	WT	ROLE	WT
Flares Illuminating Compositions Cast Flares Binder Study Epoxy Resins Sodium Nitrate Magnesium Polyester Resins						

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NIGHT OPERATIONS - THE SOVIET APPROACH

A thesis presented to the Faculty of the U.S. Army Command and General Staff College in partial fulfillment of the requirements for the degree

MASTER OF MILITARY ART AND SCIENCE

C. M. FLANNERY, MAJ, USA
B.S., Rollins College, 1973

Fort Leavenworth, Kansas
1978

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This thesis is an examination of Soviet ground force night operations, both from a historical perspective and from current doctrine and training accounts. The objective of this analysis was to determine if the Soviets can be expected to employ night operations in any future conflict, and if so, to what extent.

Historical accounts of Soviet operations during World War II reveal that night operations were an integral part of their offensive and defensive tactics. Current writings by Soviet military officials reveal that the reliance on night operations has not diminished.

Soviet ground forces today possess highly sophisticated night operational equipment, and their training programs reveal an extensive night training effort, perhaps accounting for a full 40% of all individual and unit training.

Conclusions drawn from the analysis of Soviet doctrine and training are that the Soviets can be expected to conduct night offensive and defensive operations using motorized rifle and armor forces supported by artillery and engineer units. The night operation is considered to be a natural extension of the daylight assault and conforms to the Soviet tactics of surprise, shock, and relentless pursuit.

Night Operations - The Soviet Approach

Corbett M. Flannery, MAJ, USA
U.S. Army Command and General Staff College
Fort Leavenworth, Kansas 66027

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The opinions and conclusions expressed herein are those of the individual student author and do not necessarily represent the views of either the U.S.Army Command and General Staff College or any other governmental agency. (References to this study should include the foregoing statement.)

THESIS ABSTRACT

NIGHT OPERATIONS - THE SOVIET APPROACH, by Major Corbett M. Flannery, USA, 78 pages.

This thesis is an examination of Soviet ground force night operations, both from a historical perspective and from current doctrine and training accounts. The objective of this analysis was to determine if the Soviets can be expected to employ night operations in any future conflict, and if so, to what extent.

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CHAPTER I

INTRODUCTION

BACKGROUND AND RATIONALE. In July 1976 the United States Army published FM 100-5, Operations. This document expressed in writing a previously understood but substantially undiscussed conclusion: That the forces of the Soviet Union and The Warsaw Pact nations represent the most dangerous potential adversary to the U.S. military. Because of this conclusion, these forces have become the focus for U.S. Army training and tactical doctrine. As the U.S. Army adapts to this situation, the need arises for reference materials which document the Soviet strategy, tactics, weaponry and training procedures.

The subject of this thesis, Night Operations, is one to which the Soviets devote considerable time and effort. The significance of this effort as part of their overall tactical concept is what I propose to examine.

A review of Soviet Military operations during World War II reveals that many of the most significant battles initiated by the Soviets began at night or involved extensive night preparation. Examples include the battles of Stalingrad, Kiev, Shanderovka and Berlin. At present, fully 40% of Soviet tactical exercises are oriented toward night fighting and

preparation for night operations.[1] Several of the Warsaw Pact's training areas are designed for night operations and are used exclusively for that purpose. These factors, coupled with the documented Soviet philosophy of tactical surprise and shock, establish the need for an in-depth analysis of Soviet night tactics.

The paucity of information concerning Soviet night operations is the obstacle to be overcome. Currently only two U.S. military documents deal exclusively with the subject. The first, Department of the Army Pamphlet 20-236, Historical Study, Night Combat, 1953, contains information provided by German generals who served on the Soviet front during World War II. The second document, Defense Intelligence Agency (DIA) publication DDI-1100-128-76, Soviet Ground Forces, Night Operations, March 1976, updates the first and provides information on current Soviet doctrine and training. What is still lacking for the military reader is an analysis of the level of technology associated with present day Soviet night operations, including night vision devices and night operations equipment.

RESEARCH METHODOLOGY AND THESIS CONTENT. While a paucity of information exists in U.S. military documentation, considerable amounts of information regarding Soviet night operations are available from Soviet military and open-source documents. What I propose to do is develop this information

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[1]DDI-1100-128-76, Soviet Ground Forces Night Operations, Defense Intelligence Agency, 1 March 1976, P. VIII-1.

into a single document. This technique is used extensively by intelligence analysts and should provide both a descriptive and historical product.

First, the thesis will analyze Soviet night operations conducted during World War II. The objective of this historical analysis is to determine under what conditions the Soviets favored night battles and what successes and failures they experienced. Second, it will examine Soviet night operations technology in terms of night vision equipments and weapons and material developed exclusively for night employment. This examination should establish findings regarding the extent of Soviet logistical preparation for night operations. Third, the thesis will analyze Soviet training concepts as they apply to night operations and as they differ from known daylight training concepts. This analysis will include both unit and individual training.

Fourth, I will detail Soviet night operations in terms of their present doctrine regarding night movements, night offensive and defensive operations and the night counterattack. This will involve the discussion of typical Soviet night operations using scenerios based on current doctrine and training. An example of this technique will be the description of a Soviet night river crossing involving a tank unit. Finally, the thesis will present conclusions regarding the extent of Soviet preparation for night operations in terms of equipment and training and statements detailing perceived capabilities and/or intentions for Soviet use of night operations in future conflicts.

RESOURCES. Soviet Military writings are extensive. In recent years these writings have been translated in sufficient detail to allow the western military reader the opportunity to examine previously untapped resources. Information from these documents will make up the majority of the material presented in this thesis. Such publications as Soviet Military Review and Military Herald provide monthly editions of Soviet military writings. Other sources containing significant amounts of information are the historical documents from World War II and the English language translations of Soviet training manuals. Using such open-source materials, this thesis can remain unclassified and receive wide distribution.

CHAPTER II

SOVIET NIGHT OPERATIONS - THE TRADITION

WORLD WAR II. The Nazi invasion of the Soviet Union in June 1941 began a new era with respect to Soviet military operations. At that time, the Soviet Army still functioned according to field regulations published in 1939. These regulations revealed a military theory which adhered staunchly to Communist ideology. For example, the Soviet leadership viewed the Blitzkrieg as being a bourgeois theory destined for failure.[1] The Soviet theory of war was based on the principles developed during the Civil War of 1921, calling for a rout of any attacker before momentum could be developed. This principle was the first to be abandoned by the Soviets and a more realistic concept of trading space for time was developed in the face of the German Blitzkrieg.

The military and political situation within the Soviet Union which created these strategic theories also was responsible for the organizational and equipment weaknesses of the Soviet Army. The purge of 1937 had stripped the Soviet Army of most of its experienced officers. What remained was an Army with little actual combat experience since the Civil War. The 1940 Winter War against Finland had provided some units with combat experience, however, the Stalin Cult of Personality and the Political Commisar system within the ranks denied these units any opportunity for free military

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[1]Alexander Werth, Russia At War, P 143.

thought or tactical flexibility. Although the Soviet Union possessed one of the largest engineering capacities in Europe, the lack of an automobile industry resulted in a lack of wheeled vehicles within the military. This lack of mobility dictated Soviet tactical thinking. For example, in the offensive, the ultimate objective usually was conceived to be no more than a few kilometers beyond the forward line of contact. It was inconceivable for the Soviets to attempt deep penetrations of enemy positions because of their lack of logistical mobility and rapid combat unit advancement.

In terms of equipment, the Soviet Army of 1941 lagged behind the Germans in all weapons except artillery. What armor the Soviets possessed was obsolete. The then new T-34 tank was in the production stage, however, only 1100 were available for combat.[2] Soviet radar was not tactically deployable and wireless radio was considered to be an undependable backup to their standard means of communications, the telephone. This use of wire communications proved to be both a benefit and a hinderance to the Soviet tactical commanders. The German communications intelligence effort was highly developed by 1941 but was useless against "hard-wired" communications. Conversely, Soviet commanders could command via telephone only as long as the wire remained intact and quite often they found themselves without direct communications with their subordinate units. Coupled with these equipment deficiencies was the poor state of unit and individual training

[2]Werth, P. 147.

within the Soviet Army. Most unit commanders owed their command positions to their political survivability and possessed little military proficiency.

It was under these conditions that the Soviet Army undertook the defense of the Soviet Union in June 1941. During the first German offensive, which lasted throughout the summer and autumn, the Soviets suffered costly defeats and relinquished not only territory but lost hundreds of thousands of combat troops. Still, these months of defeat served a positive purpose for the Soviet military. Alexander Werth, in Russia At War, describes these first months of war as a school of the greatest value to the officers of the Red Army, since it taught them new techniques and acquainted them with modern warfare requirements.[3] It was not until December 1941 that the Soviet Army could launch a sizable counterattack, and it was in this action that the tactics which became the base for Soviet tactics today were displayed. This counteroffensive was launched against the German forces conducting the seige of Moscow. Essentially, the Soviets seized the advantage because of prohibitive weather. Using the poor weather conditions as cover for their actions, they conducted a breakout, pursuing the retreating Germans night and day. The objective of this tactic was to create confusion among the defenders and relentlessly persist in the attack until the enemy had been routed. What the Soviets had accomplished was the incorporation of the German Blitzkrieg tactic with

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[3]Werth, P. 144.

long-established Cossack charges.[4] The counteroffensive ultimately failed because the Soviets lacked the motorized transports to continue the logistical support for the tactical units in contact. This weakness was to plague the Soviets throughout the campaigns of 1942.[5]

The Soviets had been able to accomplish their first counteroffensive because of revisions in tactical thought and the provision of sufficient quantities of T-34 tanks and Katyusha rockets. The Katyusha proved to be one of the most effective psychological and casualty producing weapons in the entire Soviet campaign. The initial use of this weapon, which at night appeared to be the simultaneous launching of hundreds of flaming projectiles, routed both German defenders and the Soviet troops in proximity to the launchers.[6] The Soviet desire to keep the weapon a secret, even from their own units, created this initial surprise and fear. As their industrial capacity grew, and more modern weapons were made available, the Soviets continued to adjust their tactics to incorporate mobility and massed forces into their military strategy.

DEVELOPMENT OF NIGHT TACTICS. The development of night operational tactics by the Soviet Army was displayed during the battle of Stalingrad. During the German seige of the city, which lasted from July 1942 until February 1943,

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[4]This is the author's analogy.

[5]Werth, P. 259.

[6]Geoffrey Jukes, Stalingrad, The Turning Point, p. 45, and Werth, P. 178-179.

the forces of Marshal Chuikov's 62nd Army displayed some of the tactics which were to be used extensively by the Soviets in later campaigns. Chuikov had correctly assessed that the German air and tank superiority favored their attacking during daylight hours. He, therefore, determined that the Soviet advantage would be at night. Following the initial German attacks during July and August, Chuikov launched his first counterattack on September 13. The attack began before daybreak, preceded by a one-hour artillery and rocket preparation fire. Initially the attack was a success but, after sunrise, the Germans were able to bring airstrikes upon the Soviets and seized the momentum away from Chuikov.[7] Chuikov did not let this lesson pass him by and immediately began to use the hours of darkness for repositioning and resupply activities. On the evenings of September 14 and 15, Chuikov moved an entire division across the Volga River and into fighting position.[8]

The tactic of night combat was repeatedly employed during the months of October and November 1942. Chuikov's forces developed the tactic of the night offensive, attacking as soon as darkness fell and maintaining extremely close contact with the enemy. This technique created a neutral zone no wider than a grenade throw and took advantage of the German reluctance to fire artillery so close to its front line. At daybreak, the Germans would counterattack and push the Soviets

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[7] Werth, P. 422.

[8] Ibid, P. 424.

back but they could not maintain the momentum after darkness. The wearing down of the German force and the tenatious counterattacks at night caused the collapse of the German offensive and led to the eventual Soviet victory at Stalingrad in early February 1943.

From the historical accounts of the defense and eventual counteroffensive at Stalingrad, several night operational tactics emerged. First, the Soviets took advantage of darkness to accomplish resupply. This vital logistical action could not have been carried out during daylight hours because of the German air superiority. Secondly, the Soviets achieved some success by launching night counterattacks while in a daytime defensive posture. In these instances, smaller Soviet forces could engage larger German units in persistent, close contact using darkness as a shield against observation by German artillery. A third tactic which was used successfully by the Soviets was the harrassment of German units at night by small bands of Soviet raiders. These harrassment techniques not only forced the Germans to remain alert at all times and therefore denied them rest, but hindered the German night resupply efforts. These night tactics were not unique to the Soviet Army, however, they represent the development of a night operational doctrine which the Soviets would use repeatedly in situations where they were outnumbered or where they did not enjoy equipment or weapon superiority.

Most historians consider the Soviet victory over the Germans at Stalingrad to be the turning point in the Eastern

Front during World War II.[9] The last major German offensive, the Battle of the Kursk Bulge in 1943, was an effort to recover from the material and psychological losses suffered at Stalingrad. This battle, which proved to be a tremendous victory for the Soviets, was the greatest armor battle ever waged.[10] From their highly fortified defensive positions, the Soviets accepted the initial German attack, absorbed it and eventually destroyed the attacker. This battle represented the last time during the war that the Soviet Army occupied a predominately defensive position and marked the beginning of the Soviet offensive which was to continue unabated through 1944 and 1945.

It was during this multi-faceted offensive that the Soviets developed and initiated much of their night offensive tactics. Perhaps the most representative of these tactics was the battle for the liberation of Kiev and Shanderovka. Both of these battles took place in the Ukrainian Offensive. Under the command of Marshal Konev, the 2nd Ukrainian Front reached the eastern bank of the Dnieper River in late 1943. On the opposite bank the Germans had supposedly constructed their formidable "Ostwall", a system of fortifications along the entire length of the Dnieper.[11] Beyond these fortifications lay the city of Kiev.

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[9] FM 30-40, Handbook On Soviet Ground Forces, Headquarters, Department of the Army, 30 June 1975, P. 2-7.

[10] Ibid, P. 2-9

[11] Werth, P. 704.

Konev ordered his troops to cross the Dnieper under the cover of darkness and to establish bridgeheads on the opposite side. During one night, approximately seven thousand Soviet troops crossed the river using small craft, improvised rafts, boards and bench seats. These troops succeeded in establishing eighteen bridgeheads.[12] With air cover provided by now available Soviet fighter aircraft, Konev was able to sustain eleven of these bridgeheads and erect pontoon bridges. During the night river crossing, 60 Soviet tanks had been sealed with putty and driven under water across the Dnieper to support the infantry.[13] This night river crossing, coupled with two night airborne drops, permitted the Soviets to establish an offensive position on the western bank of the Dnieper and attain the surprise necessary to make the subsequent attack a success. The night river crossing had been extensively planned by the Soviets, down to the use of individual fording items. The resultant campaign saw the defeat of the Germans in the Ukraine.

The defeat of the German defenders at Shanderovka was accomplished using another night tactic. Having encircled the German forces and creating a defensive pocket, Konev had succeeded in creating a situation similar to Chuikov's victory at Stalingrad. The German defenders in this case had abandoned all hope for outside relief from the Soviet pincher and were planning an action to attempt a breakout. Konev was

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[12]Werth, Russia At War, pp. 702-708.

[13]Ibid.

aware of the German situation and pressed the Soviet Air Force for bomber support for night strikes against the German positions. His objective was to deny the Germans a much needed rest and an opportunity to organize their forces for the breakout attempt. On the night of February 16, 1944, Konev called for small observation aircraft to fly over the German positions and illuminate the targets.[14] Although a blizzard was raging and the Air Force initially balked at Konev's request for bomber missions at night, the strikes were carried out. The Germans were taken totally by surprise and could not react to the slow, low-flying U-2 reconnaissance planes[15] that flew the length of their positions dropping incendiaries. The bombers followed with extremely accurate bombing of the highly illuminated targets. This surprise night attack created hysteria and total disorientation among the Germans and they were easily routed and defeated.[16]

Although the battle of Shanderovka was not significant in terms of the size of the force defeated, it provided the Soviets with a tactic which was to be employed repeatedly during the offensive campaign which preceeded the final assault on Berlin. This tactic was the use of night

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[14]Werth, P. 710.

[15]A wooden bi-plane, first built by V.N. Chioni in 1924, it was used as a pilot trainer and reconnaissance aircraft throughout WWII. Civilian designation after WWII was CSS-13. Source: Aviation in the Land of the Soviets, J. Babiejczuk and J. Arzegorzewski, translated by Foreign Technology Division, USAF, 23 Sep 1971, P. 42-47.

[16]Werth, P. 710.

illumination of a target force, not just for aerial bombing but for the attack by armor, cavalry and infantry units. Marshal Zhukov, the Soviet Union's premier commander during World War II, described this technique in an interview for Komsomolskaya Pravda, detailing the preparation for the attack on Berlin.

> We concentrated a huge striking force on the bank of the Oder: the supply of shells alone enough for a million artillery rounds on the first day of the storming. To stun the German defenses immediately, it was decided to begin storming at night with the use of powerful searchlights. Finally the famous night of April 16 began. No one could sleep. Three minutes before zero hour we left our dugout and took up places at our observation posts. To my dying day I will remember the land along the Oder, blanketed in April fog. At 5:00 A.M. sharp it all began. The Katyushas struck, over 20,000 guns opened fire, hundreds of bomber planes roared overhead...and after 30 minutes of fierce bombing and shelling, 140 anti-aircraft searchlights employed every 650 feet in a line, were turned on. A sea of light swept over the enemy, blinding them, and pointing out in the darkness the objects of attack for our tanks and infantry.[17]

Zhukov's description of these initial moments of the Battle of Berlin reveal the purpose for the night tactic of illumination: surprise and psychological impact, both on the enemy and friendly forces.

An analysis of Soviet offensive operations during the final years of World War II reveals that the Soviets saw the importance of night operations and developed and employed night tactics successfully. They made use of the cover of darkness to breach obstacles and cross rivers; they conducted logistical and reconnaissance actions at night in order to

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[17] Reprints from the Soviet Press, April 30, 1975, pp. 25-34.

facilitate daylight operations; they made use of illumination for target acquisition and for orientation of attacking forces; and they initiated attacks at night to achieve the element of surprise. All of the above tactics, as well as the defensive night tactics displayed at Moscow and Stalingrad, have endured and are part of the Soviet Army doctrine today.[18] These experiences, coupled with the technology developed since World War II, provided the base for the present day Soviet night operations policy, strategy and doctrine.

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[18]DDI-1100-128-76, P. III-1.

CHAPTER III

TECHNOLOGY AND TRAINING

NIGHT OPERATIONAL EQUIPMENT. The Soviet Army emerged from World War II with a basic tactical principal of exploitation of an enemy through firepower. Heavy emphasis today is placed on nuclear and chemical warfare and alternative means in conventional conflict to achieve surprise, decisive force and deep maneuvers. The Soviets stress surprise with emphasis on denying the enemy time to react. This surprise is achieved by secrecy of planning, camouflage and deception, limiting the time spent in combat preparation, and the execution of decisive and preferably unexpected maneuvers.[1] One of these unexpected maneuvers is the attack during darkness. Once surprise has been achieved, the tactic of relentless pursuit is employed until the enemy is routed and destroyed.

To accomplish these tactical goals, the Soviets have developed ground force weapon systems which are highly mobile, rugged and which operate under all weather and battle conditions. Soviet armor, for example, is less designed for crew comfort as it is for simplistic maintenance procedures and all weather conditions. Motorized infantry vehicles and self-propelled artillery systems are equally mobile and rugged.

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[1]FM 30-40, Handbook on Soviet Ground Forces, Headquarters, Department of the Army, 30 June 1975, P. 5-1.

All of these weapons and equipments possess night operational devices. substantiating the Soviet emphasis placed on night operational capabilities. It is the technology associated with this equipment which gives the best indication of the Sovlets' intentions regarding night combat. It is unlikely that the Soviets would devote considerable research and development efforts into an area they view as being of little tactical importance. Current Soviet night operational equipment reveals an advanced technology and consists of a variety of infrared devices and night vision aids for driving and battlefield surveillance. Likewise, Soviet ground force units are equipped with a variety of illumination and darkness defeating systems.

The APN series of infrared sighting equipment has a range of approximately 150 to 950 meters as is employed on Soviet recoilless guns and antitank and field guns of 57 to 100 mm. Similar night sighting equipment is known to be installed on the T-54, T-55 and T-62 medium tanks.[2] The PPN series of infrared sighting devices is employed on Soviet light and medium machineguns of 7.63 and 12.7 mm.[3] The distances of target observation associated with the APN and PPN series are presented in Figure 1.

Binocular head sets, such as the PVN 57, are used for navigating infantry and artillery vehicles and some over-

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[2]CPT Eugene D. Betit, Soviet Technological Preparation for Night Combat, Military Review, March 1975, P. 91.

[3]DDI-1100-128-76, Soviet Ground Forces, Night Operations, Defense Intelligence Agency, 1 March 1976, P. III-4.

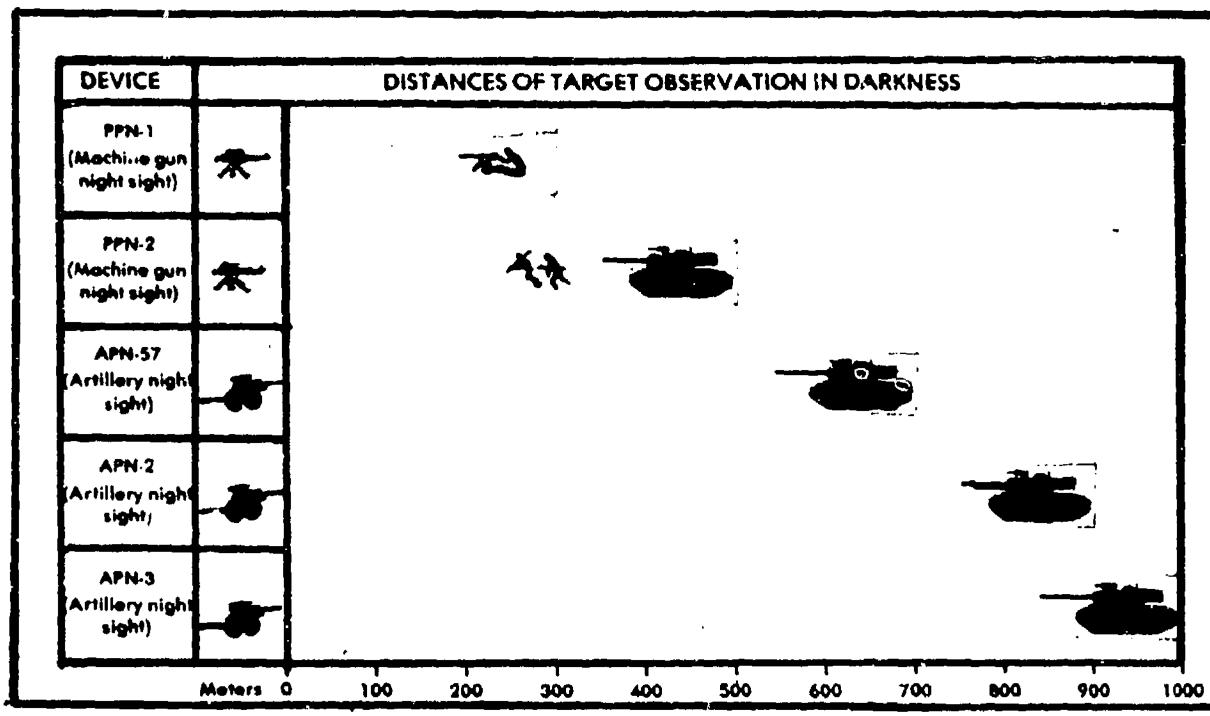

Figure 1 General characteristics of Soviet night vision devices.

DDI-1100-128-76, Soviet Ground Forces, Night Operations, March, 1976.

sized engineer equipments. Passive infrared field glasses are provided to Soviet troops and selected marksmen are armed with the Dragunov (SVD) sniper rifle mounted with an infrared detection device for firing on enemy active infrared systems.[4]

Night navigational equipment in the Soviet inventory is extensive and technically advanced. The three basic configurations of this equipment are the directional gyroscope, coordinate and course indicators and the most sophisticated, a system that plots the vehicle's course on a topographical map. The latter system is available on command vehicles (BTR 50) in motorized rifle and armor units.[5]

Many Soviet combat vehicles, including all medium tanks and scout cars (BRDM), carry either the GPK 48 or GPK 59 gyroscopic compass. These compasses can reflect the vehicle's course (asimuth) within two degrees for periods of up to 1.5 hours before they must be resurveyed. Some Soviet writers indicate that if the equipment is properly surveyed prior to starting, and if the start data is exact, these vehicles may be driven for five hours before resurveying is required. The gyroscope is switched on while the vehicle is motionless and it must remain stationary for at least five minutes while the operator surveys his position. Before movement, the directional angle or magnetic azimuth of the

[4] Betit, P. 91.

[5] Ibid

vehicle's longitudinal axis must be determined and entered into the gyro.[6] This system is apparently used extensively during night river crossings when snorkeling gear is used and during night marches overland.

The second type of device, the coordinate and course indicator package, is used by artillery units to establish survey data. The system consists of a gyroscopic indicator, control panel, route indicator, coordinate display, two course indicators and a transformer. Average error for this system is no more than 1.3 percent of the course covered, with the gyroscope being accurate to ± 20 feet over a half-hour period.[7]

The navigational system used by commanders, usually in the BTR 50 command vehicle, includes a map plotting console plus course and route indicators. The error of the gyroscope course indicator is, according to Soviet articles, ± 20 feet per hour. The device continuously provides the vehicle's coordinates and the azimuth while plotting the route as it is covered. Map scales of 1:25,000, 1:50,000 and 1:100,000 may be used with the device. Once set in motion, the device is left on as long as the vehicle is moving. The gyrocompass requires four or five minutes to wind down after the equipment is switched off.[8]

Illuminating devices are the other major items of

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[6]Majs. E. Krylov and Sch Balaban, <u>Tank Orientation Using Compass</u>, Military Herald, November 1972, P. 93.

[7]Betit, P. 93.

[8]Ibid.

Soviet night operational equipment which are employed during offensive and defensive training and operations. The Soviets possess a wide range of illuminating devices, including illuminating cartridges, rockets, shells, aerial bombs, searchlights, mortars, tracer shells, flare rockets and luminous road signs and markers.[9] These devices are employed to improve visibility or to blind the enemy and to combat his illumination support equipment.

The Soviet employment of illumination prior to the Battle of Berlin is described in Chapter II. In that example, illumination was used to both blind the enemy and reveal his location to attacking Soviet forces. In such operations, illumination may be periodic or continuous. Usually, continuous illumination is reserved for the main attack, when capturing centers of resistance or assaulting fortified areas. The basic principles in the employment of illumination devices by the Soviets appear to be surprise and massing. Massing is achieved through a consecutive concentration of the bulk of illumination equipment along the main line of advance.[10]

The Soviets consider radius, intensity and duration important in determining which particular device to use. Aerial flares producing one million candlepower of illumination, burn three to six minutes and provide a circle of illumination with a diameter of .5 to 4 kilometers, depending on their

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[9] DDI-1100-128-76, P. III-3.

[10] Ibid, P. III-4.

height from the ground and weather conditions. An artillery star shell illuminates ground for 30 seconds over a circle 500 to 1,500 meters in diameter. Illuminating cartridges with a range of 200 to 350 meters will burn for seven seconds and will illuminate an area of 200 to 240 meters in diameter.[11]

In addition to the sighting, navigational and illuminating devices discussed here, the Soviets possess surveillance radars and seismic sounding devices which help defeat the conditions of darkness. The complete inventory of Soviet night operational equipment was not discussed here; however, those items discussed provide a representation of the current Soviet technology in the area of night equipment.

It appears that the Soviets have approached the subject of night operational equipment seriously and have devoted considerable research and development efforts to create highly advanced devices, navigational aides and sighting apparatus. Their use of illumination, both historically and in current descriptions of training, indicate a continued reliance on darkness defeating or enhancing devices. Their overall technology with respect to night operational equipment appears to be as good as any in the world.

NIGHT OPERATIONAL TRAINING. Proper training of the individual soldier to the Soviets is the basic requirement for victory in battle. This principle is especially true for night operations. Regardless of the changes in tactics, techniques and equipment, it is the individual soldier who

[11] DDI-1100-128-76, P. III-4.

must do the actual fighting. The Soviet approach to training the individual for night fighting enhances all other individual combat training and is apparently part of a training system that is carried throughout section, squad, platoon, company and larger unit training.

Night conditions have an especially strong adverse effect on the poorly trained soldier for he is neither physically nor psychologically prepared to meet the conditions of night combat.[12] The Soviets preface almost all of their writings on night training with the statement that night training should be conducted only after the individual soldier has mastered the skills required for daylight combat. These skills include map reading, weapon familiarization, firing techniques and range estimation. After these skills have been demonstrated, the soldier is considered ready for night training. Most individual training of this type is conducted during the basic training phase, however, the continuous enhancement of night combat skills is carried on in unit training.

One of the first training tasks in individual training is orientation to night conditions. The soldier is taught to orient himself at night by learning to select and recognize orientation points which may escape his attention during the daytime. With the recognition of orientation points and his knowledge of map reading, he is able to locate himself in his

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[12] DDI-1100-128-76, P. VII-1.

sector of the battlefield.[13]

The individual soldier also receives training in recognizing different sights and sounds and in estimating their range and direction. The following ranges represent the Soviet standards for recognition at night:

Visibility

Source	Distance in Kms
Headlights of motor vehicles and tanks	4 - 8
Muzzle flashes from single cannons	4 - 5
Muzzle flashes from small arms	1.5 - 2
Bonfire	6 - 8
Flashlight	up to 1.5
Lighted match	up to 1.5
Lighted cigarette	up to .8

Audibility

Source	Distance
Cannon shot	up to 15 kms
Single shot from rifle	2 - 4 kms
Automatic weapons fire	3 - 4 kms
Tank movement	
-on a dirt road	up to 1.2 kms
-on a paved road	3 - 4 kms
Motor vehicle movement	
-on a dirt road	up to 500 m
-on a paved road	up to 1 km
Small arms loading	up to 500 m
Metal on metal	up to 300 m
Conversation of a few men	up to 300 m
Steps of a single man	up to 40 m
Axe blow, sound of a saw	up to 500 m
Blows of shovels and pickaxes	up to 1 km
Screams	up to 1.5 kms [14]
Oars on water	up to 2 kms

In the conduct of this training, the individual soldier is taught that directions from which sounds originate cannot always be determined with a high degree of certainty. Weather

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[13] DDI-1100-128-76, P. VII-2.

[14] Ibid, P. II-1, II-2.

conditions, such as rain, can affect both audibility and visibility and natural noises, such as thunder, can conceal movement.

The Soviet soldier is given a number of training problems which he must solve in total darkness, without the aid of night vision or illumination devices. This training attempts to prepare the soldier psychologically for night combat and develop initiative and resourcefulness. The problems are based as much as possible on actual combat conditions.[15] In addition to psychological and physical training, the Soviet soldier receives a considerable amount of political training to reinforce the other training and to make him reliable and confident.

The final phase of individual night training involves the specialized training associated with the individual's military job. All vehicle drivers, communications specialists, engineers and chemical specialists receive individual night training in those skills before assignment to their units. Once assigned to a particular unit, these skills are enhanced through unit training.

Once the Soviet soldier has completed his basic training and has been assigned to his unit, he begins a more detailed and demanding training schedule. Soviet military writers attest to the emphasis placed by all units on night combat training. The most significant theme throughout this training is the great attention to detail and the preparation

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[15] DDI-1100-128-76, P. VII-2.

for night training exercises. In motorized rifle units, it is not unusual to have two weeks preparation, during daylight conditions, for a one or two night firing exercise.[16] In an article on night firing training involving a rifle company, Soviet Major N. Melnichuk describes some of the preparation:

> Initial skills in handling weapons in the dark (by touch) are acquired by the company personnel during daytime training. Supervised by the sergeants and platoon leaders they learn how to load (unload) their weapons, fill magazines and so on. If a trainee fails to do some action properly the instructor shows the correct way to do the job and then makes the trainee repeat the action till he can do it without a hitch.
>
> In mastering night fire techniques, it is advisable to observe the following procedure: first to fire at illuminated targets (with the terrain lit up all the time or periodically) and then at dark targets (silhouettes projected onto the sky or a fire glow) including firing by gun flash and by shot. This sequence of fire training is based on the principle of setting the trainees gradually complicated missions.[17]

Melnichuk continues by describing how the company is taken from one specially constructed firing range to another until all night firing conditions are met. As the troops gain experience firing under night conditions, the training progresses to firing as units, whether it be by squad, section or platoon. Figures 2 through 8 depict how Soviet night firing training sites are constructed and used. At Site One, squad RPK light machinegunners and riflemen armed with AKM assault rifles engage pop-up and moving targets. At Site Two they are taught to sight and to dryfire at stationary targets and to

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[16]CPT E.D. Betit, Soviet Training for Night Warfare, Military Review, September 1975, P. 80.

[17]MAJ N. Melnichuk, Night Fire Training, Soviet Military Review, January 1977, P. 24.

throw grenades at illuminated targets. At Site Three the company personnel are trained in determining distance at night. Usually following Site Three training, the platoon conducts a live firing exercise at ranges of 100 to 500 meters.[18] At Site Four, BTR gunners fire the on-board machineguns at moving and pop-up targets and attempt range determination. At Site Five, grenadiers using the RPG grenade launcher engage moving targets representing armored personnel carriers and tanks.[19]

A sixth site is used by company machinegunners using the PK machinegun to fire on pop-up and moving targets. The final firing site is a Control Training Site, used for graded firing using sub-caliber weapons. Here the ranges are greatly reduced, often to 20 meters.[20]

Night training for Soviet armor units emphasizes both firing techniques and vehicular movement and navigation. In the case of these units as much as two months preparation may be taken prior to a night live-firing exercise. Armor units establish training points similar to those used by rifle units, with orientation on conditions of darkness being gradually intensified until the tank gunners and drivers are familiar with illumination, semi-darkness and total darkness conditions.

Normally, three sites are constructed for this progressive training. At Site One, tank crews conduct gunnery

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[18] LTC E. Sokolov, From Infantry Weapons at Night, Military Herald, February 1971, P. 93.

[19] Betit, P. 81.

[20] Col. A. Egorov, Night Fire Training, Military Herald, January 1972, PP. 102-104.

practice on rocking frame simulators. Electric lightbulbs are popped to simulate the dazzle from the tank's main gun muzzle flash. At Site Two, individual crew functions are performed and range estimations and azimuth determinations are practiced. At Site Three, tank crews simulate firing on targets displayed at various ranges. Following successful completion of these three phases, the crew conducts a live-fire exercise and is graded, with the grades recorded for future reference.[21] During live-firings, both night and normal range finding devices are used so that gunners can gain an appreciation for the reduced effective range under night conditions.

Navigational skills are perfected using the navigational aides described earlier in this chapter. All vehicle drivers must prove themselves competent by navigating a course at night and arriving at a pre-designated position within a certain time constraint.

Upon examination of the vast amount of articles on night training written by Soviet military writers, it is apparent that not only do the Soviets consider night combat to be important, but they consider it necessary. Approximately 40% of the unit training conducted by Soviet combat arms units is in preparation for or involved with night operations. This preparation and attention to detail is in keeping with the historical significance placed on night operations, their tactical doctrine of continuous pursuit and their considerable efforts toward developing night operational equipment.

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[21]Betit, P. 83.

The Soviets appear to be capable night fighters, perhaps more so than our own forces. Their soldiers are individually prepared both psychologically and physically for night combat and their units are well trained in the night firing, ranging and navigational skills. Although the Soviets have not participated in sustained night operations since World War II, it appears that they are capable of such an undertaking.

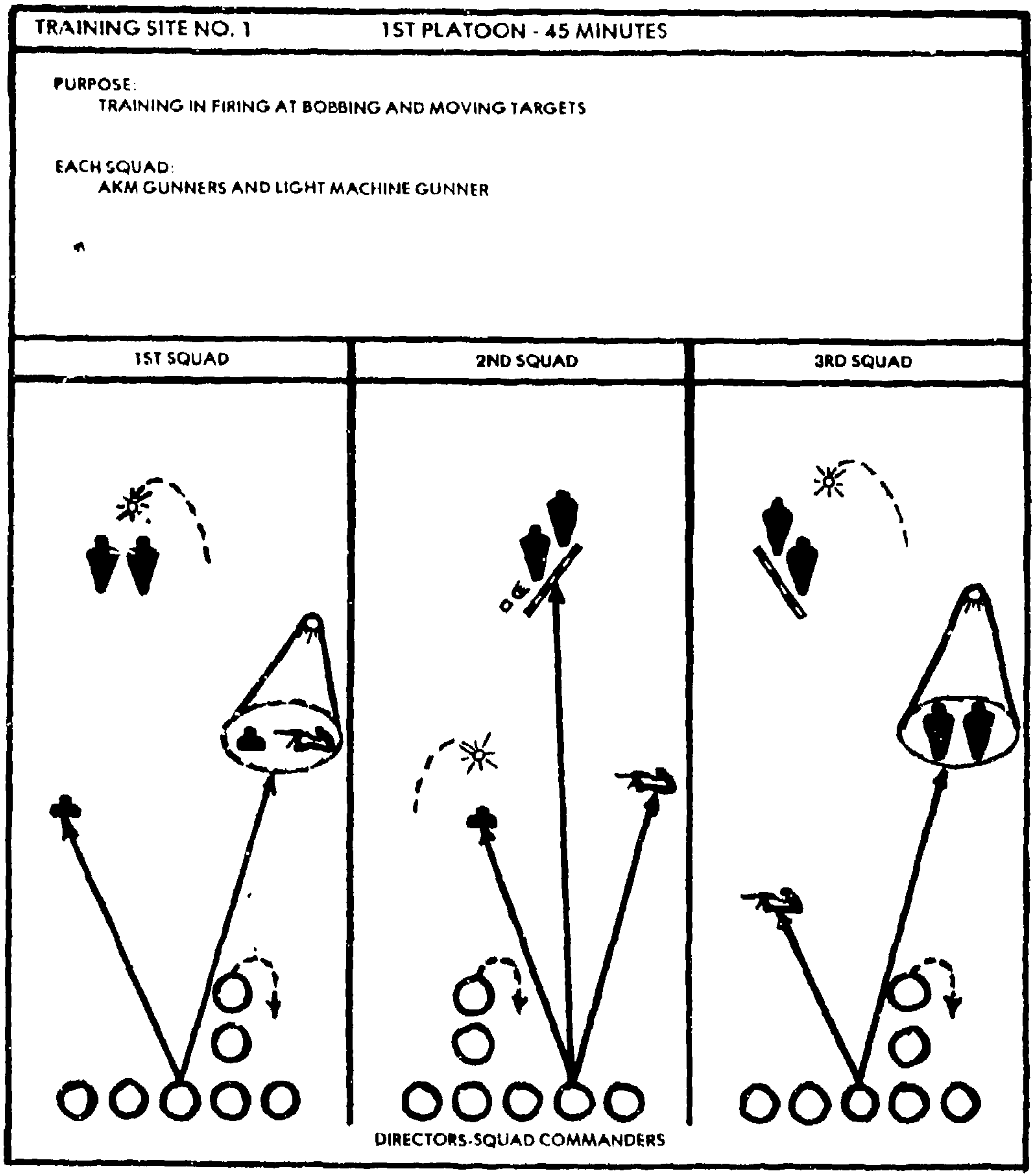

Figure 2 Firing Range

DDI-1100-128-76, Soviet Ground Forces, Night Operations, March 1976.

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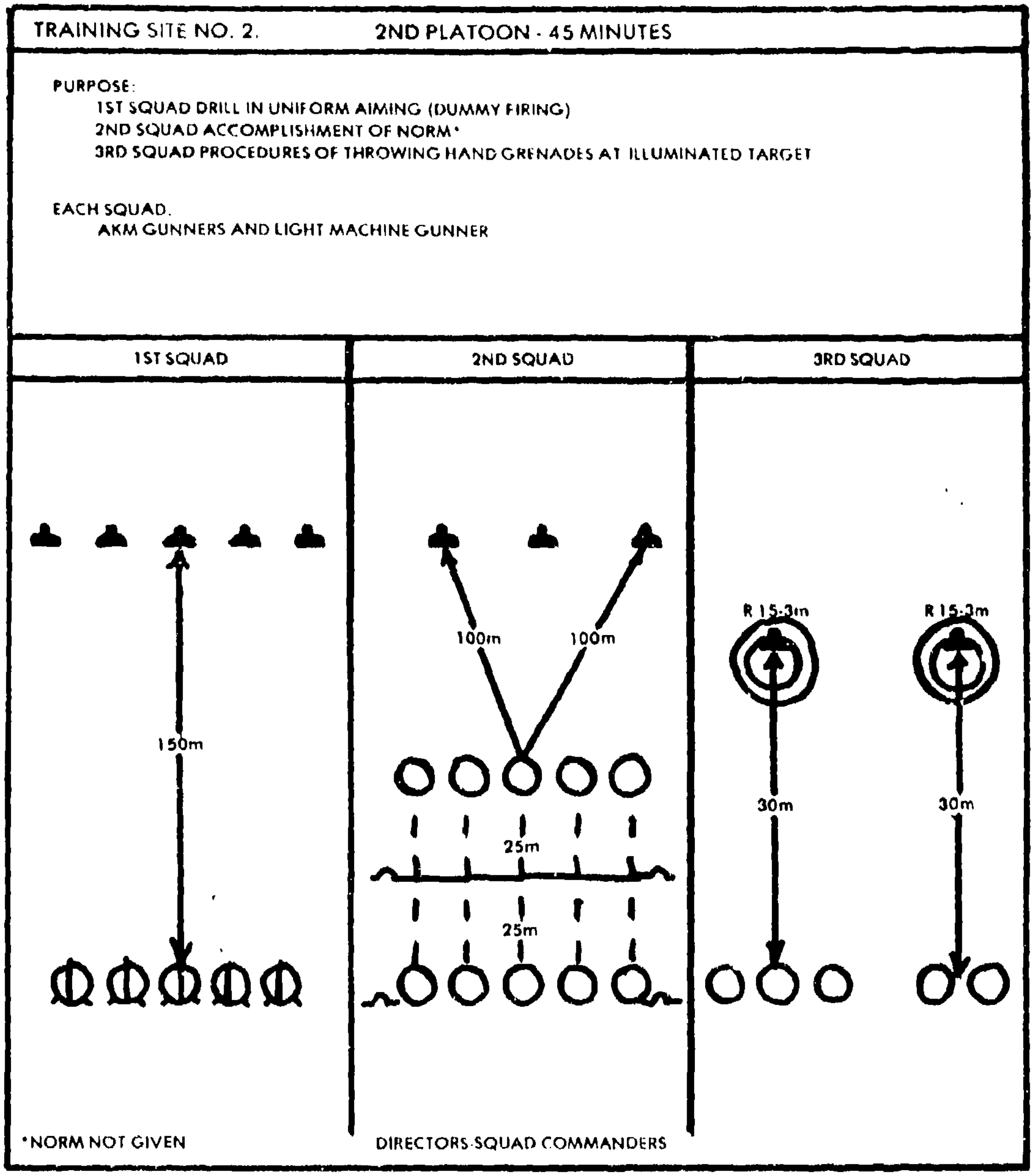


Figure 3 Firing Range

DDI-1100-128-76, Soviet Ground Forces, Night Operations, March 1976.

TRAINING SITE NO. 3	3RD PLATOON - 45 MINUTES

PURPOSE
1. METHODS OF DETERMINING DISTANCES UNDER NIGHT CONDITIONS
2. DRILL IN PLATOON FIRE CONTROL

EACH SQUAD.
AKM GUNNERS AND LIGHT MACHINE GUNNER

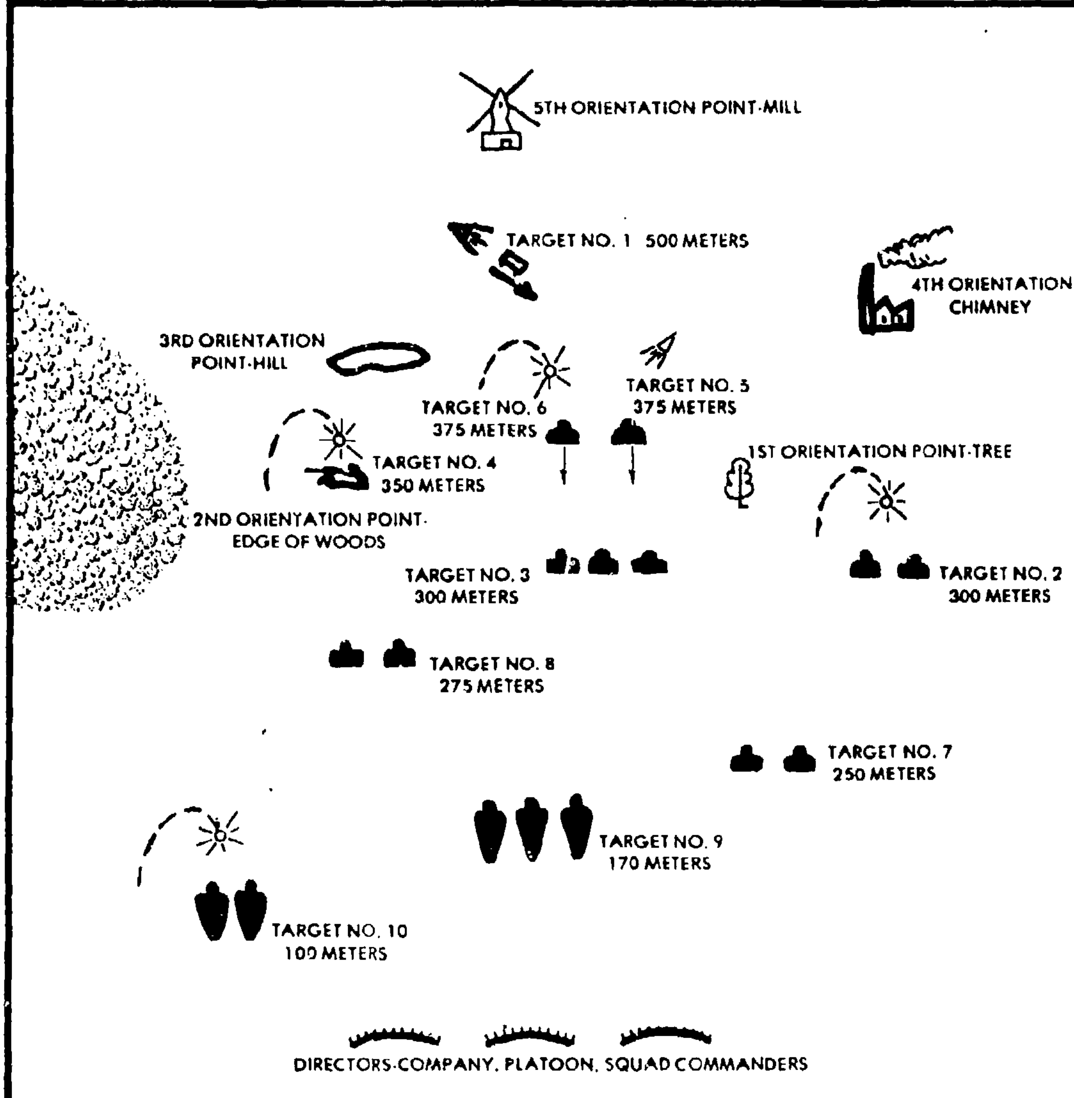


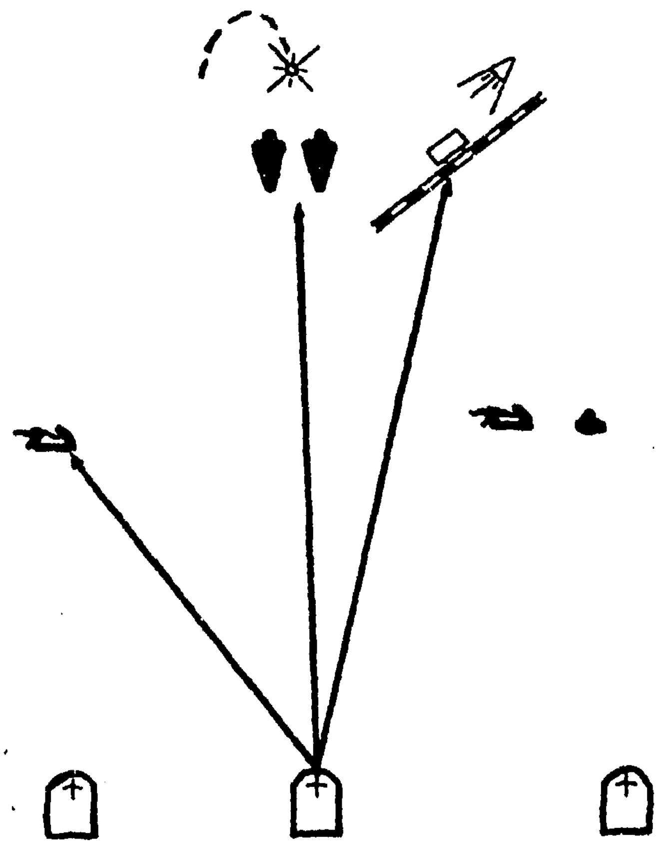
Figure 4 Firing Range

DDI-1100-128-76, Soviet Ground Forces, Night Operations, March 1976.

TRAINING SITE NO. 4. APC GUNNERS - 135 MINUTES (3x45)

PURPOSE:

1. TRAINING FOR FIRING AT BOBBING AND MOVING TARGETS
2. DETERMINATION OF DISTANCES TO VARIOUS TARGETS
3. ACCOMPLISHMENT OF NORMS NO. 4 AND NO. 9*



*NORMS NOT GIVEN

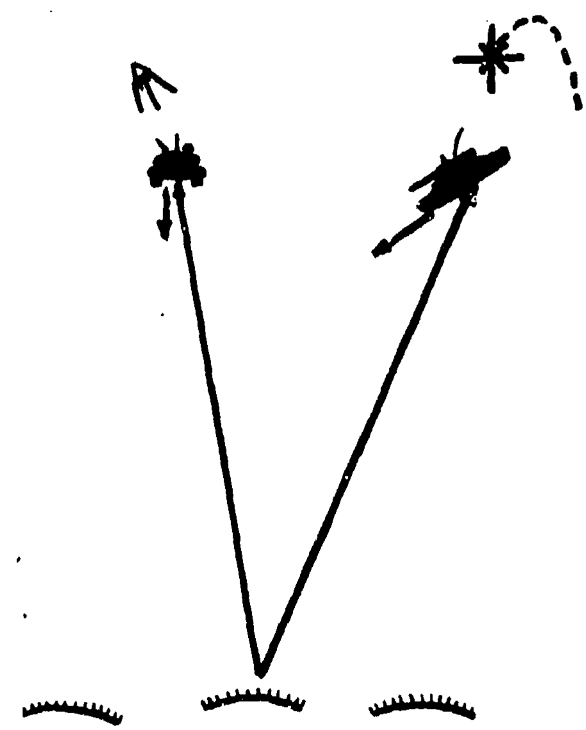
Figure 5 Firing Range

DDI-1100-128-76, Soviet Ground Forces, Night Operations, March 1976.

TRAINING SITE NO. 5. GRENADA LAUNCHER OPERATORS - 135 MINUTES (3x45)

PURPOSE:

1. TRAINING FOR FIRING AT MOVING TARGETS
2. ACCOMPLISHMENT OF NORMS NO. 5*
3. DETERMINATION OF DISTANCES TO VARIOUS TARGETS



DIRECTOR DEPUTY COMMANDER OF FIRST PLATOON

*NORM NOT GIVEN

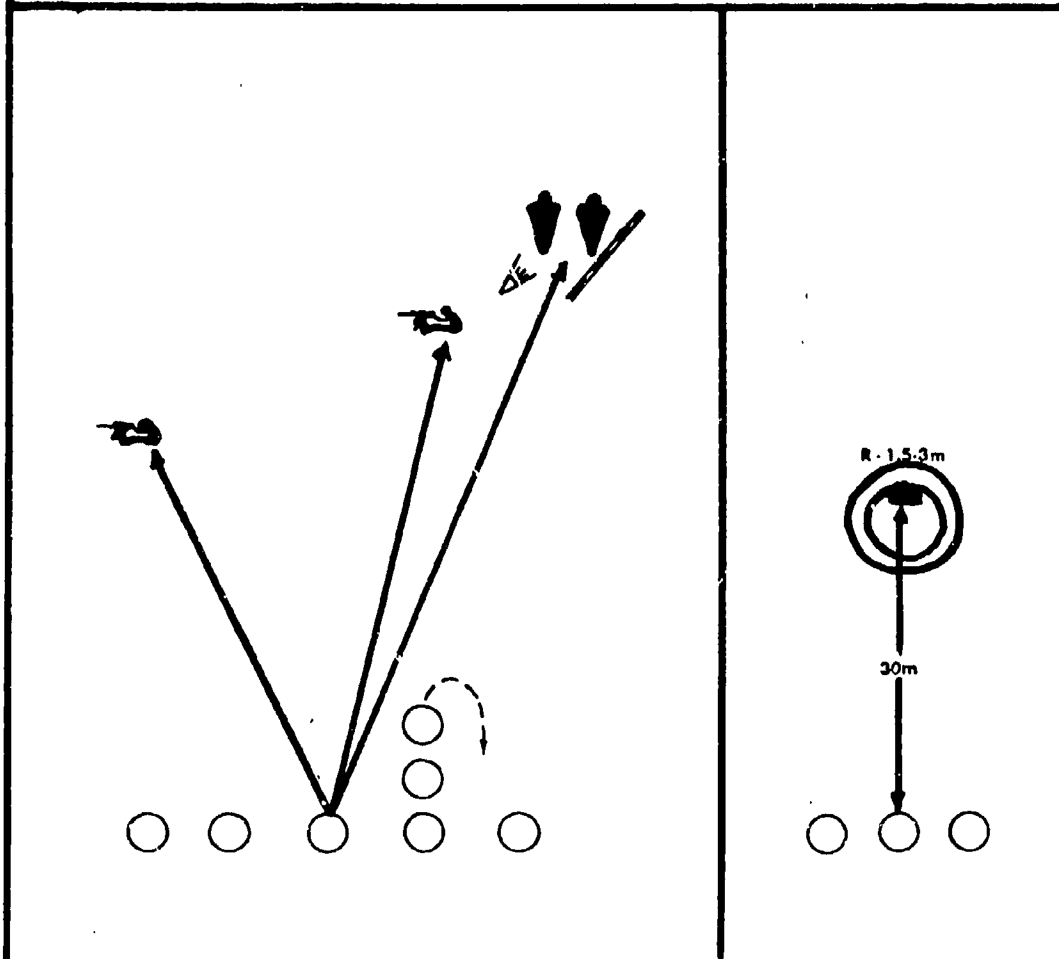
Figure 6 Firing Range

DDI-1100-128-76, Soviet Ground Forces, Night Operations, March 1976.

TRAINING SITE NO. 6. MACHINE GUN SQUAD - 135 MINUTES (3x45)

PURPOSE:

1. TRAINING FOR FIRING AT BOBBING AND MOVING TARGETS
2. ACCOMPLISHMENT OF NORM NO. 5* METHODS OF HAND GRENADES LAUNCHING.
3. DETERMINATION OF DISTANCES TO VARIOUS TARGETS



*NORMS NOT GIVEN

DIRECTOR SQUAD COMMANDER

Figure 7 Firing Range

DDI-1100-128-76, Soviet Ground Forces, Night Operations, March 1976.

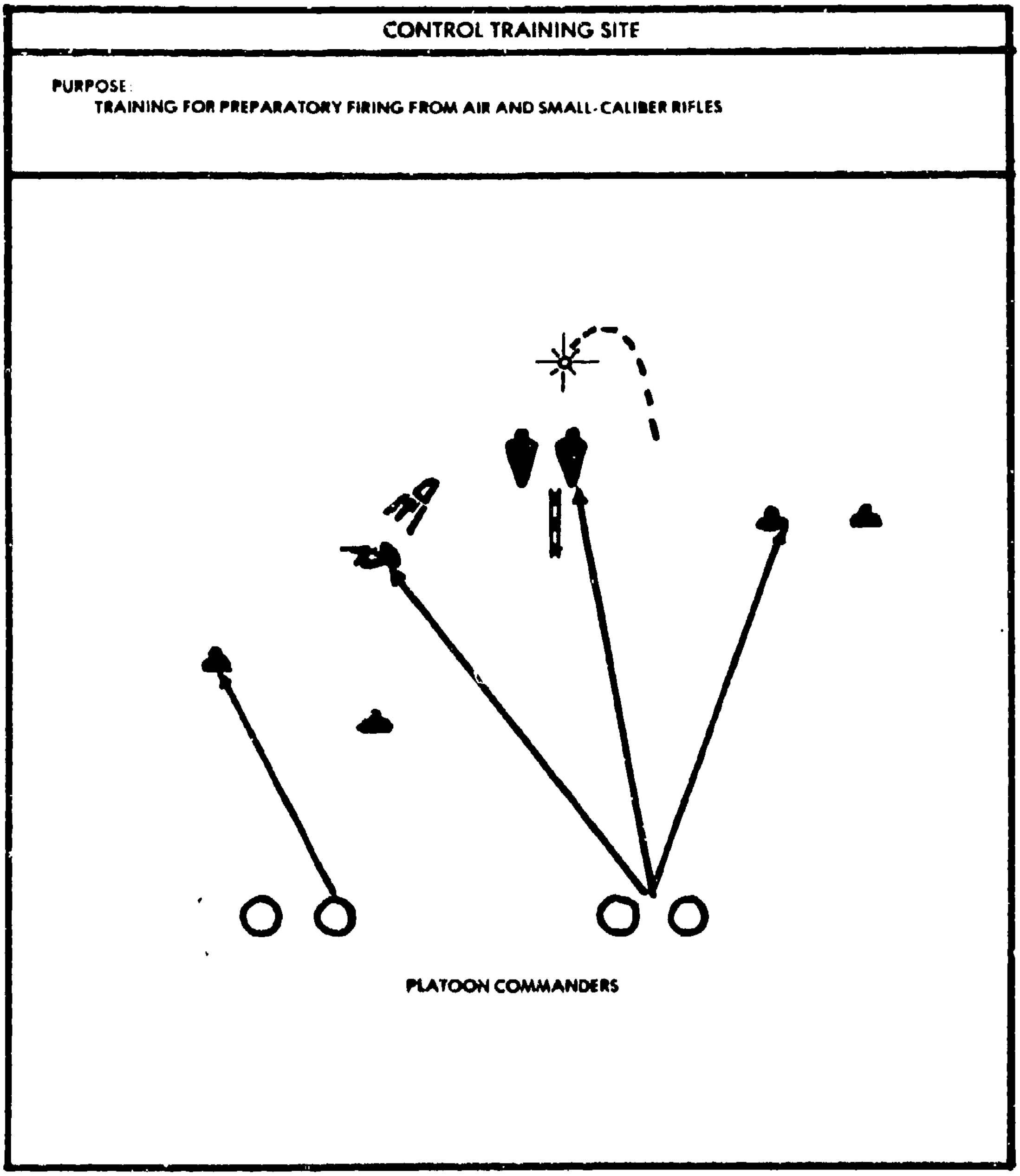


Figure 8 Firing Range

DDI-1100-128-76, Soviet Ground Forces, Night Operations, March 1976.

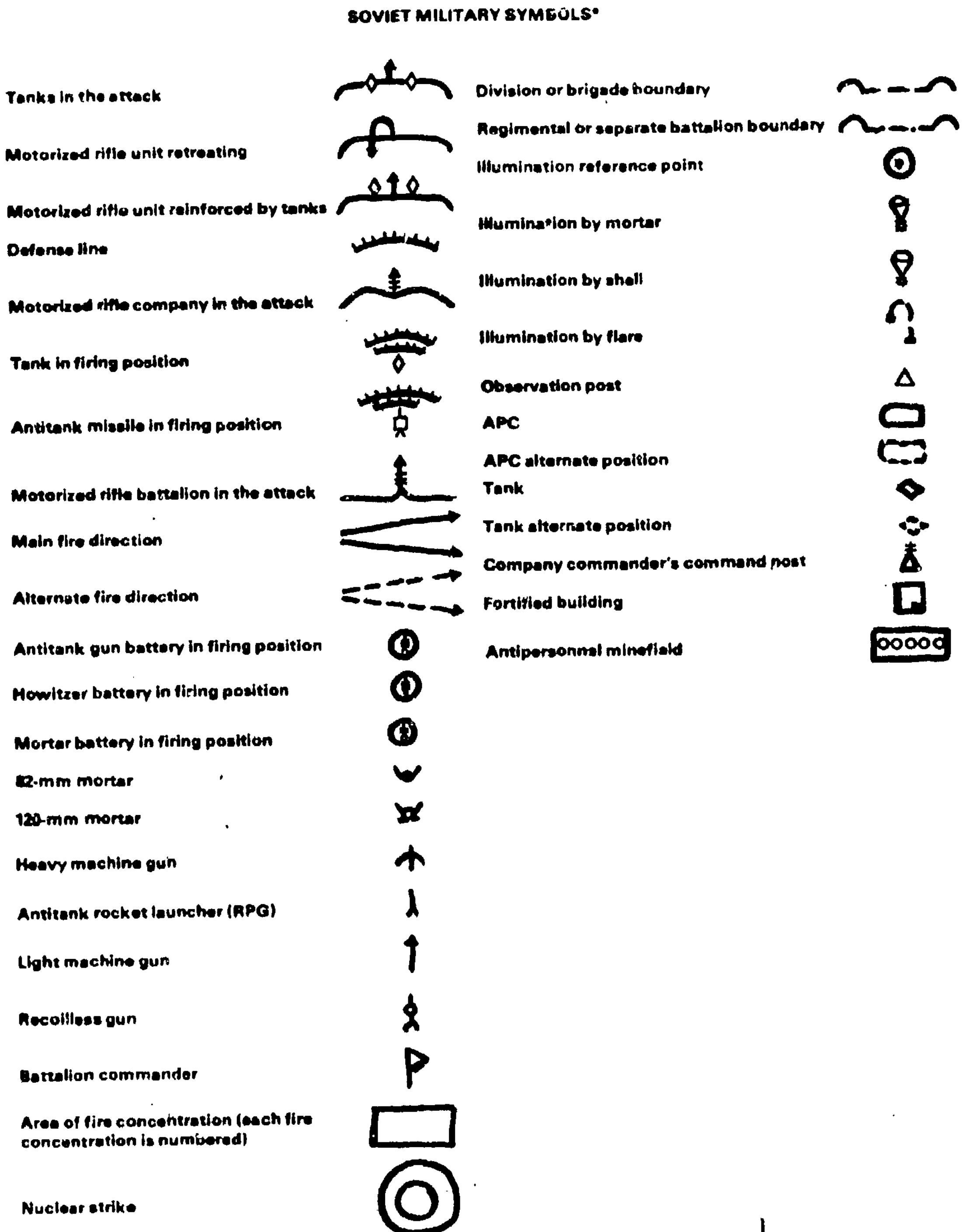


Figure 9 Soviet Military Symbols.

*AP-220-3-18-70-INT, Soviet Armed Forces Military Symbols, October 1970.

CHAPTER IV

NIGHT OPERATIONS

Soviét writings reflect that night operations are considered to be part of an overall tactical scheme and, as such, are seldom, if ever, planned as solitary actions. The mission of a particular unit, as well as subsequent missions, dictates when and where night operations will be conducted. Soviet writings stress that no pattern should be established for timing night offensive operations.[1] It does appear, however, that night attacks launched after sunset are preferred to predawn attacks because preparation, reconnaissance and coordination measures can be conducted in the late afternoon hours rather than under conditions of darkness.

Preparation is the common link for all Soviet night operations, whether they be armor, motorized infantry or combined arms. The extensive efforts put forth by commanders in getting ready for night operations is yet another measure of the Soviets' intentions regarding the use of night warfare in any future conflict. Commanders at all levels work out detailed plans of attack to include night march formations, maneuver schemes, security measures, phase and coordination lines and recognition means. This chapter examines the night march, a formation common to all Soviet operations, and

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[1]CPT Eugene D. Betit, Soviet Tactical Doctrine for Night Combat, Military Review, August 1975, P. 22.

details how various combat and combat support units function during night offensive and defensive operations. Included are examples of night attacks involving motorized rifle and armor battalions and companies and the artillery, engineer and logistics support provided for each.

THE NIGHT MARCH. The night march is an essential element of night combat operations since darkness provides the concealment necessary for units moving into attacking or defending positions. Soviet military theorists maintain that night rates of movement on well-lit nights should equal or exceed similar daytime operations.[2] Under conditions of extreme darkness, the rates may drop to less than half the daytime rate.

Soviet combat forces employ a column formation for night marches. The column is organized to provide for the rapid movement and security of the column and to avoid the need to re-form in the event of a night meeting engagement with the enemy. In the case of regimental size marches, artillery, tanks and engineers are placed at the head of the column along with local inhabitants or other personnel familiar with the area to be traversed.[3] Figures 10 and 11 depict battalion and regimental advanced party configurations.

On the march, the commander is at the head of the main column. When the battalion moves as part of a regimental

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[2]Betit, P. 22.

[3]DDI-1100-128-76, Soviet Ground Forces, Night Operations, Defense Intelligence Agency, 1 March 1976, P. IV-1.

column, the battalion commanders and his staff are always located at the head of the battalion column.[4] The operational order issued by the senior commander includes the following:

1. Information on the enemy and possible contact points.
2. Missions of subunits and their routes.
3. Information on adjacent units and units or recon elements operating in front of the column.
4. Composition and task of the security forces, route and time of passing departure and control points.
5. Formation of the column, speed of movement, rest halts, action to be taken upon contact with the enemy, and location of the commander and his deputy.[5]

The progress of the column depends on its composition. A column of wheeled vehicles alone normally travels at 25 to 30 kilometers per hour while a tank or mixed column can maintain a rate of 15 to 20 kilometers per hour.[6] Soviet theorists recommend rest halts of 20 or 30 minutes duration every two or three hours. During these stops, the column deploys two to four kilometers off the road and parallel to it. During these rest stops the use of light and other coordination measures are extremely restricted. As with all Soviet operations, the use of radio communications between units is limited to short transmissions between authorized personnel. The Soviets prefer to communicate and coordinate actions through the use of messengers, often on motorcycles.[7]

During the march, security units are located closer to the main body than during the day. Flank security would maintain a distance of not more than five kilometers, while

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[5] DDI-1100-128-76, P. IV-1.

[6] Ibid.

[7] Ibid, P. IV-5.

front and rear security elements would keep a three to five kilometer distance as opposed to eight to ten kilometers for flank security and 10 to 12 kilometers for front and rear security elements. Reconnaissance elements would scout at a distance of one to three kilometers in front of the security element. Engineer elements reconnoiter roads, rest stop areas and lines of deployment and overcome obstacles or locate routes around them.

The meeting engagement, the Soviets' most favored offensive operation during daylight, is similarly anticipated at night. Soviet commanders believe their superior preparation and discipline of units will favor their exploitation of any night meeting. In such an encounter, subunits of the main force deploy simultaneously from the line of march within the operational zone and execute turning or enveloping movements.[8]

The use of the night march by the Soviets is not limited to the offensive but is considered a primary means of resupply, reinforcement and withdrawal from contact. The composition of a night march column is dictated by the purpose for the march. For example, resupply missions are likely to have less rear security forces or reconnaissance elements.[9]

OFFENSIVE OPERATIONS. The night offensive, as employed by the Soviets, can be used to accomplish different objectives. A night attack may be the continuation of a daytime combat operation or it may be initiated as a separate action to achieve

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[8]DDI-1100-128-76, P. IV-6.

[9]LTC Z. Shutov, Pursuit, Soviet Military Review, March 1975.

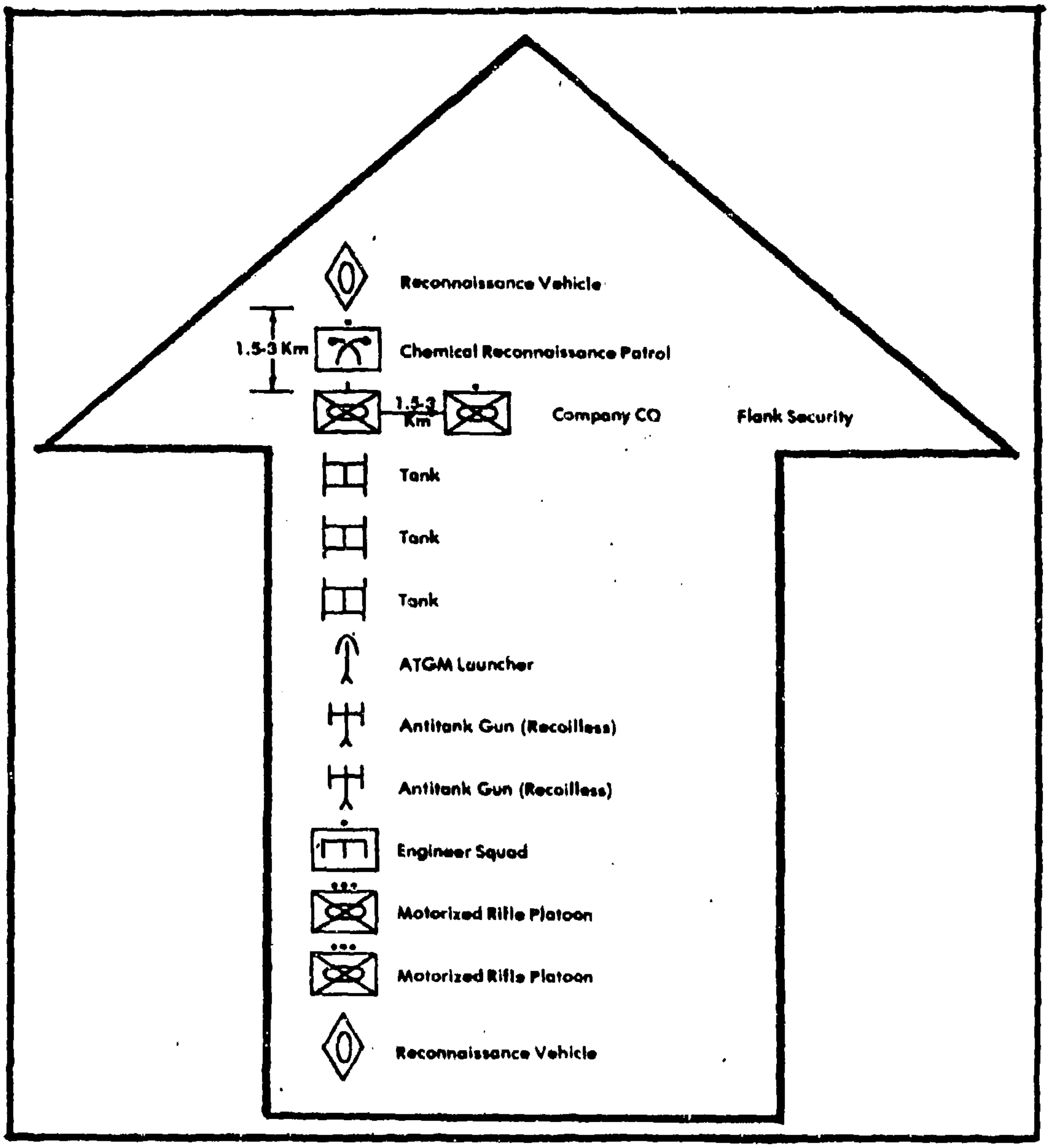

Figure 10 Motorized rifle company (reinforced) as battalion advance party. A type approach formation and column organization.

DDI-1100-128-76, Soviet Ground Forces, Night Operations, March 1976.

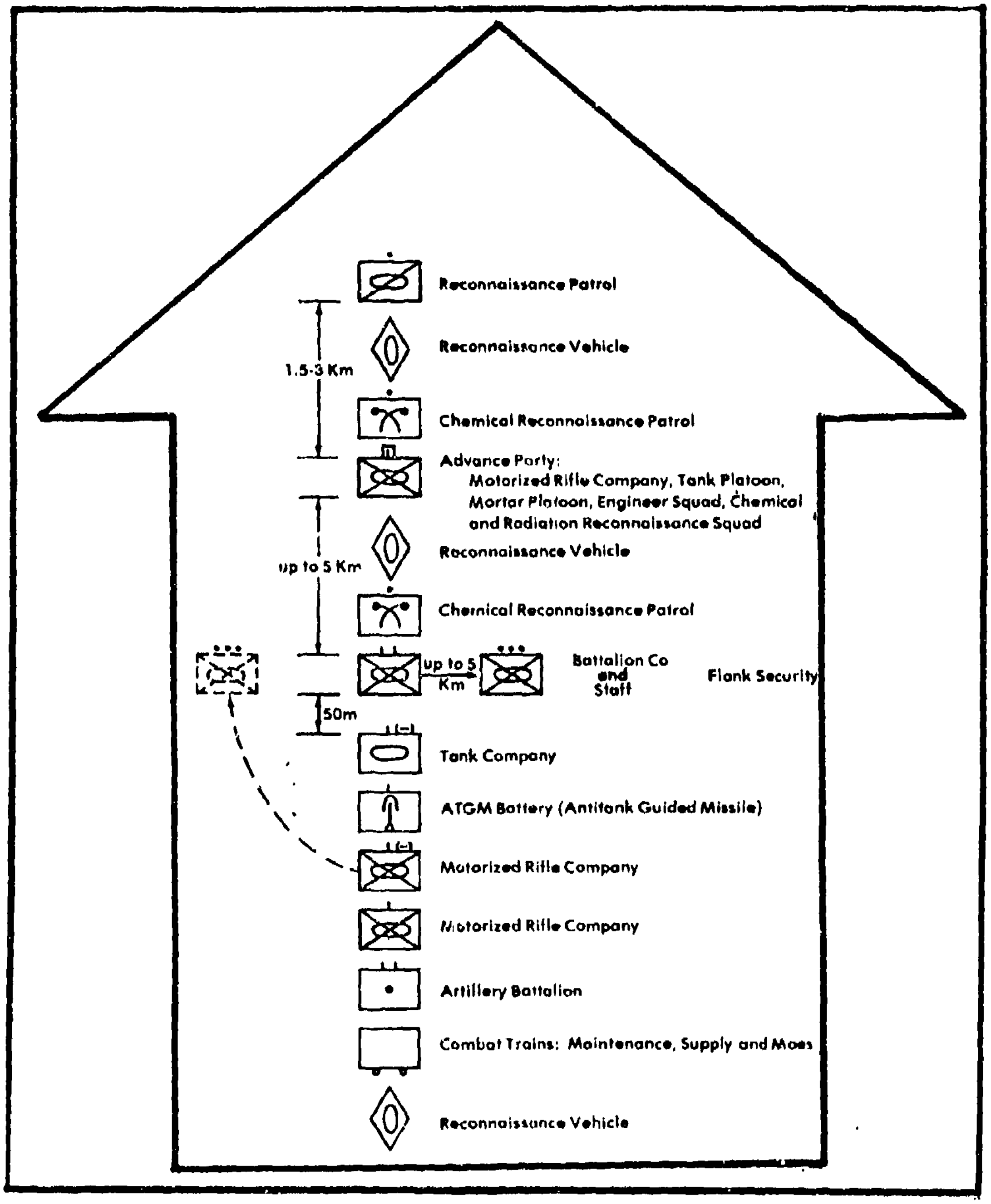

Figure 11 Motorized rifle battalion (reinforced) as regimental advance guard. Approach formation and column organization.

DDI-1100-128-76, Soviet Ground Forces, Night Operations, March 1976.

a limited objective, such as the breaching of enemy defenses. As the continuation of a daylight combat action, it is important for the Soviets to convert to night operations without a break in the action. This relentless pursuit or exploitation, the result of much planning and extensive training, is basic to Soviet operational art. As a separate or initial offensive action, the night offensive is used to achieve surprise or shock an enemy. The Soviets consider the psychological shock of a night attack to be as significant as the surprise achieved.

The principal elements of a Soviet night attack are always present, regardless whether the attack is to be conducted by armor or infantry alone, or by a combined force. These elements include detailed planning, extensive reconnaissance and complete control by the command element. While the details of each of these elements might vary with each situation, their presence is considered a must by Soviet theorists.

MOTORIZED RIFLE NIGHT OFFENSIVE OPERATIONS. The most common configuration for motorized rifle units attacking at night is the battalion-sized attack, usually supported by a battalion of artillery and a company of tanks. The primary mission for an attack of this size would be to penetrate enemy defenses as rapidly as possible and to create confusion for exploitation by subsequent larger unit attacks. The motorized rifle battalion would be responsible for conducting its own reconnaissance and preparing a detailed plan of

attack.[10] The battalion commander would normally conduct a visual reconnaissance of enemy-held territory, provided observation vantage points are available. Following this, the commander would provide subordinate commanders with a detailed description of the unit's area of responsibility, azimuths for each subunit's approach and final assault and definitive boundaries to be observed. Subordinate commanders would then inspect their equipment and night vision devices and receive issue of flares, illumination and tracer rounds.[11]

The battalion commander's attack plans cover a wide range of activities, many of which are unique to night operations. Each subordinate unit will be provided plans for reconnaissance, air defense measures, employment of reserves and definitive recognition and communication plans. It is not unusual for the battalion to attach artillery batteries to motorized rifle companies for direct support during an attack. Since most attacks involve a final assault on foot, detailed plans must be made and coordinated for dismount locations and arrival times.

Prior to departing the assembly area, personnel will apply white or light colored armbands so that recognition and coordination can be effected in route to the disembarking areas. Tanks and APCs are marked with white or luminescent panels, each unique to the subunit.[12] The route to the line

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[10]Betit, P. 23.

[11]Ibid.

[12]Ibid.

of attack is designated by markers which are 80 to 100 centimeters high, and from that line forward the direction of attack will be marked with distinctive markers for each company or platoon.[13]

During the tactical march to the line of departure, drivers are required to use night vision devices to ensure they are operable. Radio silence is maintained, with all radio sets placed in the receiving mode in order to monitor any emergency instructions from the command element.[14] Once the line of departure has been reached, the infantrymen may disembark and proceed on foot or ride on the rear of accompanying tanks.

The battalion attacks with all three of its companies on line, with supporting armor, engineer and CBR units attached to each company. The battalion reserve is usually held for employment against the flanks of any enemy counterattack, allowing the first echelon units to continue their pursuit unabated. This reserve is normally no more than a reinforced platoon.[15] Occasionally, reserve forces will be used to exploit a perceived weakness or enemy flank in order to achieve rapid, deep penetration of their defenses.

The motorized rife company is normally the smallest Soviet unit to conduct an independent night attack. When an independent attack by a company is required, the unit is

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[13] DDI-1100-128-76, P. V-3.

[14] LTC B. Nazarenko, Battalion Night Attack, Military Herald, January 1972, P. 11.

[15] Betit, P. 24.

normally reinforced with armor, artillery, engineers and chemical units. The preparation for the company attack is much the same as the battalion attack with the exception that all details for the attack are memorized by the platoon leaders and the attack may be carried out without additional directions or coordination.[16]

The company commander formulates a night vision device and illumination plan, including the designation of illumination teams. Illumination means available to the company include rockets, signal flares and searchlights. Other factors considered essential in the company plan are the designation of azimuth takers and lead and supporting platoon formations.[17]

Following a visual reconnaissance by the company commander, the operational order is provided to each platoon leader and is committed to memory by all. This order would contain, as a minimum, the order of movement to the assault position, the location for dismount of APCs, the sequence of platoon movements along passages in mine fields (if appropriate), order of cover by fire, reference points, places for light alignment, directional markers and routes for bypassing obstacles.[18]

Once the company arrives at the platoon dismount points, the attack usually begins with each platoon having a different approach toward a single objective or position to be overrun.

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[16]DDI-1100-77-76, The Soviet Motorized Rifle Company, Defense Intelligence Agency, October 1976, P. 118.

[17]LTC A. Averyanov, Night Attack, Soviet Military Review, November 1975, P. 26.

[18]DDI-1100-77-76, P. 119.

If enemy resistance is light, the company may attack mounted or on the back of attached tanks. The company normally attacks on line with no reserve.[19] Variations of this formation are possible and one Soviet writer described a situation where the tanks maintained a static "overwatch", destroying positions and sources of illumination. The infantry had dismounted on the reverse slope of a hill and attacked behind a lead tank. Artillery was used to provide illumination and as direct support or direct fire when the attack began to bog down. Emphasis was placed on small subordinate units (squads, sections) infiltrating through gaps in the enemy defenses. A counterattack was repulsed with the assistance of the artillery.[20] The article which described the attack emphasized that night vision devices were used when illumination was not available. This represents a continued adherence to the historical tactic of using illumination to both reveal the enemy and guide attackers over and around obstacles. The Soviets apparently do not view illumination as taking away any of the psychological or surprise advantage achieved by night attack.

While most Soviet writings regarding night operations of motorized rifle units identify operations conducted as independent actions, much attention is given to the conversion from day to night operations and the continuation of a daylight attack after dark.

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[19]DDI-1100-77-76, P. 119.

[20]Ayeryanov, P. 27. (Note: The referenced attack was a training exercise.)

ARMOR NIGHT OFFENSIVE OPERATIONS. Like the motorized rifle battalion, the tank battalion represents the most common formation for night armor attacks. Unlike motorized infantry, however, tank attacks are limited to acceptable terrain and are restricted by requirements for mounted attacks. Armor does provide unique advantages for night use, including night sighting devices and navigational equipment and built-in illumination sources.

Soviet armor rarely performs night attacks without accompanying infantry, whether dismounted or in APCs. On moonlit nights, tanks may assault ahead of infantrymen taking the lead and providing illumination support as well as firepower. Under conditions of less visibility, tanks may position themselves on line with infantry or serve in an overwatch position. Under some conditions, engineers may be employed to lead armor elements through minefields or around obstacles, then accompany the tanks into the attack, fighting as infantry.[21]

Preparation for a night attack by a tank unit is similar to that conducted by a motorized rifle unit. Often the direction of attack, route of pre-attack march, and line of departure are dictated by navigational restrictions, thus relieving the commander of some planning requirements. Still, the reconnaissance, illumination plans, directional markers, and coordination instructions must be accomplished in detail.

A tank battalion commander plans night attacks and

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[21] Betit, P. 24.

conducts reconnaissance with his company commanders during daylight, if possible. If time permits, a reconnaissance is also conducted during darkness so that the difficulties of control, coordination, and illumination can be resolved.[22] Normally, the course or route of march for the attack is determined by the tanks' directional gyroscopic equipment, which, as outlined in Chapter III, is as reliable as any known to exist today. While navigation and directioning are problems for tank crews at night, the most significant problem is one of acquiring and ranging targets. Changing from day to night sights and functioning in a darkened turret creates unique problems for the gunner and loader.

Following equipment and night vision device inspections and issuance of additional fuel and special illumination and tracer ammunition, the tank units maneuver into a march configuration for travel to the line of attack. Each tank will be equipped with luminescent panels or red lights on the rear of the turret for recognition. Covered routes to the assault positions are used when available in order to counter the effects of enemy night detection devices. If no covered routes are available, tanks move to their line of deployment under the cover of artillery. Usually a short, intense artillery preparation is fired immediately prior to launching the attack.[23] Figure 12 represents the control

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[22]DDI-1120-129-76, Soviet Tank Company Tactics, Defense Intelligence Agency, May 1976, P. 40.

[23]Ibid, P. 40.

measures taken by a tank unit during the night march and assault of enemy positions.

On order, the tank companies lead the assault, attacking along predesignated routes. Since navigational equipment is often required to maintain the specific assault azimuth, any redirection to avoid obstacles requires reorientation and a return to the original azimuth. Two techniques are employed for ranging enemy weapons and positions using active infrared (IR) devices. Two tanks may obtain azimuths to the target and, using triangulation, compute the range.[24] This technique requires the tanks to communicate with each other, normally by radio, thus increasing their vulnerability to electronic warfare measures. The second measure calls for one tank to adjust the fire of another by directing their fire.[25] Here again, verbal communication is required.

During the assault, Soviet tank crews fire either while on the move or from a short halt. The halt-fire situation makes the tank vulnerable since muzzle flash provides excellent illumuniation for enemy gunners. Firing on the move is employed when the night sight or coaxial machinegun is used. When the main gun is fired as an indirect fire weapon, the halt-fire situation is used.[26]

As a rule, the Soviet tanks attack on a straight line since they are following a predetermined azimuth. One Soviet

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[24]Betit, P. 26.

[25]Ibid.

[26]Ibid.

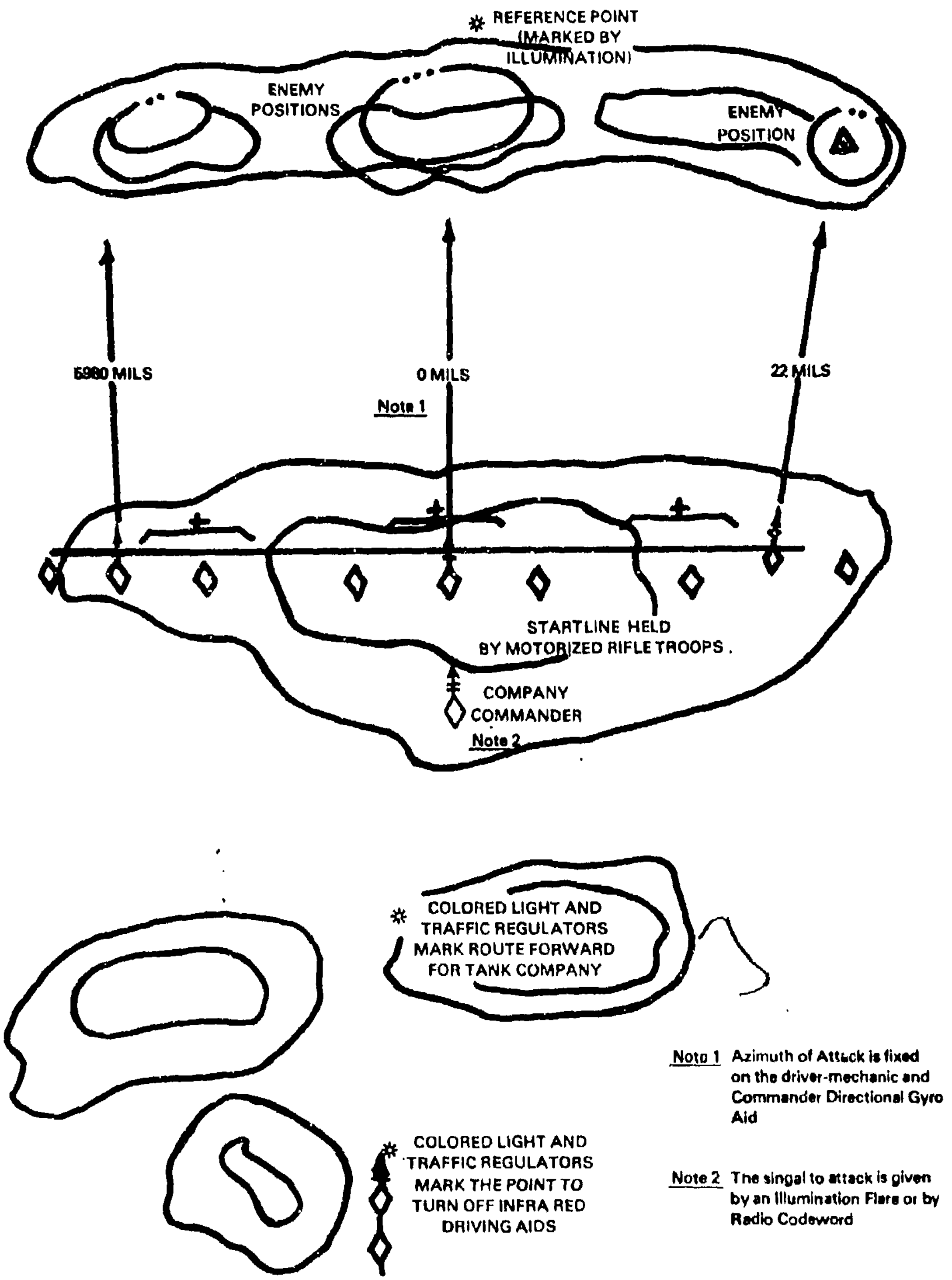

Figure 12 Control Measures for Night Attack

DDI-1120-129-76, Soviet Tank Company Tactics, May 1976.

writer describes an account where Soviet tank crews maneuvered to the flank and rear of enemy positions and approached with their lights on. The enemy mistook the Soviet tanks for their own reinforcements and allowed the armor to close uncontested.[27] In another case, the Soviet tank commander had his crews turn on their night driving lights and closed ranks with a withdrawing enemy who mistook them for their own rear security forces.[28] It should be considered then that, while the rule is generally inflexible regarding night armor attacks, the Soviets apparently will adapt to the situation.

Soviet tactics are likewise not limited to head-on assaults. Another common practice is to advance with tanks along a route parallel to a withdrawing enemy that has been routed by motorized rifle units. This allows the tanks to attack the flanks of the retreating enemy at will and to exploit gaps in the enemy's defenses.[29]

If a tank force commander encounters a superior enemy force during a night attack, he may order temporary positions to be selected and call for artillery fire. The principal rule, however, is the maintenance of the tempo established by the surprise night attack, with operations continuing through the following day.

WATER OBSTACLES. The river crossing, one of the most difficult military maneuvers under the best conditions, is

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[27] LTC V. Kokhanov, Pursuit, Soviet Military Review, June 1975. (Note: the author was apparently providing accounts of an actual Soviet operation during WW II)

[28] Ibid.

[29] Ibid.

considered to be a significant tactical operation by Soviet armor units at night. Several World War II battles were initiated by the Soviets following a night river crossing by armor units. Today, Soviet T-62 and T-72 tanks are equipped with snorkeling equipment which allows for night or day crossings. Figure 13 depicts the Soviet approach to the river crossing using tank forces. Tank companies in the reconnaissance role are reinforced by engineers, divers, and chemical specialists to survey river banks to find suitable crossing sites.[30] Reconnaissance elements also seek to identify existing bridges or fording sites as well as enemy positions on both banks.[31]

Tank companies employed as security detachments seize crossing areas identified by the reconnaissance elements and attempt to use shallow fords to establish a bridgehead on the far bank. The near banks of crossing sites are held until the arrival of the main body if an enemy is present and prevents an immediate crossing. A company in the main body crosses the obstacle using either fords or established crossing sites under the cover of the security detachments. After crossing, it moves along a predesignated route to its objective. If a battalion has no security elements, a company will cross after intensive concentrations of artillery and tank fire.[32] As seen in Figure 13, the objectives for the main body attack are

[30]Most underwater survey work is conducted at night, even for daylight operations.

[31]DDI-1120-129-76, P. 45.

[32]Ibid.

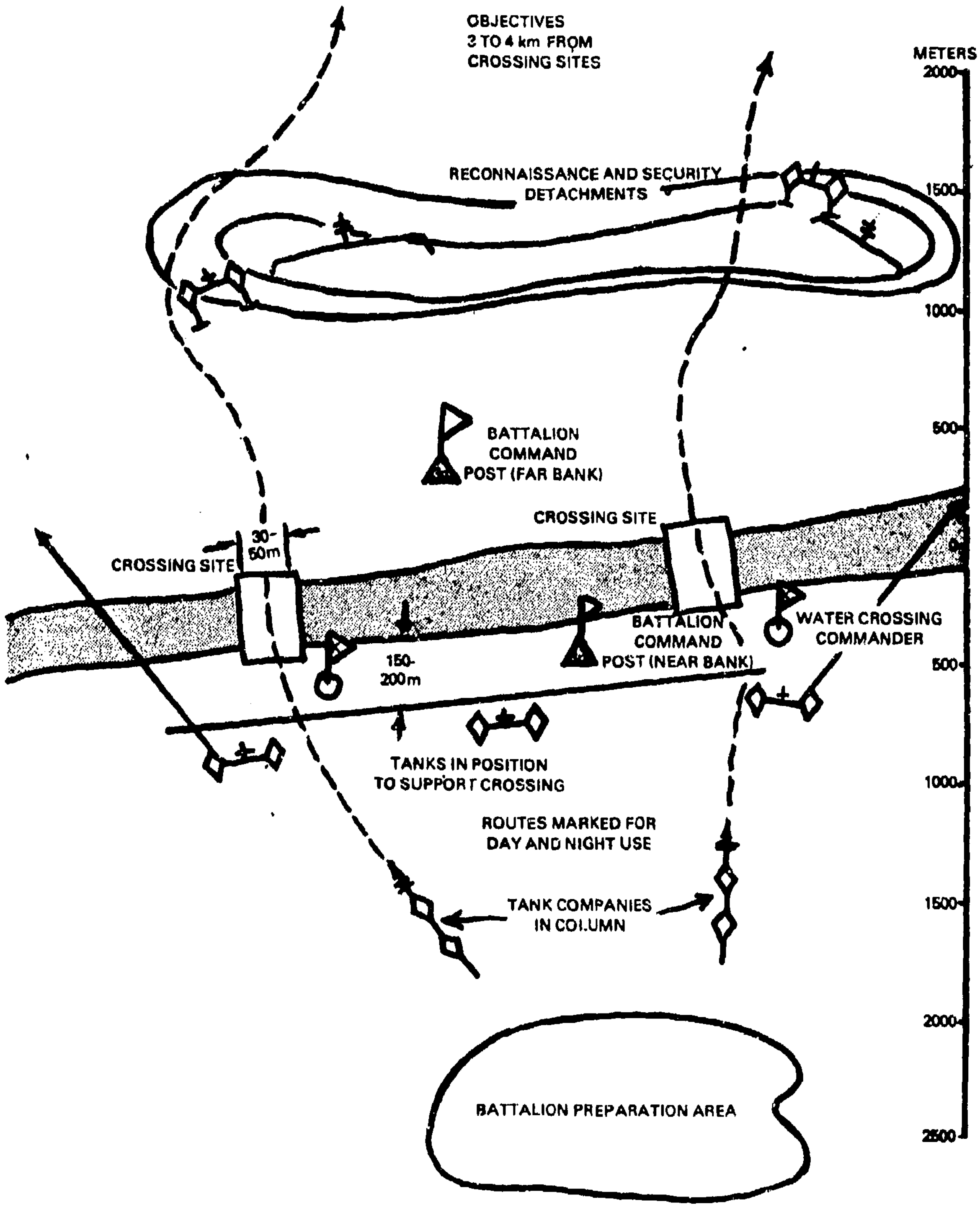

Figure 13 Crossing Control Organization.

DDI-1120-129-76, Soviet Tank Company Tactics, May 1976.

usually limited to three or four kilometers distance from the crossing. Any greater distance, whether a daylight or night objective, would place the attack in jeopardy from flanking movements.

COMBINED ARMS NIGHT OFFENSIVE OPERATIONS. The employment of a combined arms force in night operations represents the most common Soviet tactic and presents the most formidable attack force. Multiple battalion attacks, using tank and motorized rifle task forces, allow the Soviets to make use of mounted or dismounted infantry and armor firepower to assault formidable enemy positions and built-up areas. With armor in the lead, mounted infantry can be used when enemy resistance stiffens, dismounting and engaging the enemy on foot.

The distance between tanks and motorized rifle units depends on the degree of illumination, trafficability of the area, and the characteristics of the enemy's defense. On a brightly lit night or during intense illumination, tanks may be located 100 to 150 meters from the motorized units. Such a distance provides close support by tanks and uninterrupted coordination between armor and infantry. Distances will be shortened if the area of operations is not well illuminated.[33] The width of the front will also depend on local conditions. A battalion front of 1.5 to 2 kilometers, the normal daylight formation, may be decreased to one kilometer, depending on illumination and terrain. Company fronts, for both tanks and motorized rifle units could decrease from the normal 800 meters

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[33]DDI-1100-128-76, P. V-5.

to 400 or 500 meters in darkness conditions. When the infantry attacks on foot, the squad front is approximately 60 meters, with 40 meters between squads, thus giving a dismounted platoon a 400 meter front.[34]

ARTILLERY IN THE NIGHT ASSAULT. Soviet doctrine calls for extensive use of artillery preparation fires as preludes to all offensive operations. It is during night operations, however, when Soviet artillery is fully utilized in a variety of rules designed to support the attack. However, in some Soviet accounts, the artillery preparation is not used because of the loss of surprise. This practice does not appear to be the rule, but, silent night attacks were launched during World War II by the Soviets and they cannot be discounted in future situations.

In addition to serving as the principal fire support weapon for motorized rifle and armor attacks, the artillery can be employed to provide illumination, mark targets, lay smoke barrages, or to fire marking rounds for other weapon systems. The artillery battalion attached to a motorized rifle battalion for a night offensive may be directed to fire incendiary rounds upon preselected enemy targets, thus facilitating the attacking forces' navigation.[35]

The Soviets' use of illumination during night attacks is extensive. Artillery units are normally called on to fire illuminating rounds during key stages of combat or during the

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[34]DDI-1100-128-76, P. V-5.

[35]Betit, P. 26.

entire operation. Continuous illumination would occur, as a rule, only when the Soviets are engaged in fighting for key objectives or to repulse enemy counterattacks.[36]

Because of the problems inherent in moving towed or self-propelled artillery pieces and ammunition carriers cross-country at night, the Soviets tend to employ artillery command posts and firing positions close to roads. Other problems encountered at night are difficulty in selecting and surveying firing positions, target reconnaissance, fire adjusting and redeployment to new firing positions. To overcome some of these, Soviet doctrine calls for artillery units to be emplaced during daylight and firing data prepared in advance.[37]

During night operations, control of artillery fire is decentralized, with the artillery commander being collocated with the commander of the supported unit. In some cases, "accompanying artillery" is attached to frontline motorized rifle companies to ensure the repulse of counterattacks and the destruction of enemy tanks and strongpoints.[38] This direct fire role greatly increases the firepower of the motorized rifle company since, during night operations, each company is likely to receive its own artillery battery from the artillery battalion attached to the motorized battalion.

Soviet artillery employs a variety of target acquisition measures in support of night operations. Optics,

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[36]Betit, P. 26.

[37]Ibid.

[38]Ibid.

sound, radar, topographic aids, meteorlogical devices, and ground surveillance all play a role in developing a target acquisition picture. Photographs of the battlefield, taken by artillery units during night firings, are compared with photos taken of the same area during daylight and often reveal enemy locations. Artillery illumination allows for optical reconnaissance and during periods of no illumination, infrared devices are used. Sound ranging is used extensively by the Soviets, who believe it is twice as effective at night due to sound propagation characteristics.[39] Data charts are prepared in advance for various distances based on three variations of air temperature.[40]

Soviet artillery radar is used to detect moving targets or large objects which extend above the terrain surface, and for counterbattery fire. An additional duty in nuclear situations would be to determine ground zero on nuclear bursts.[41]

Antiaircraft artillery positions are equally difficult to establish at night. Unless prepositioned during daylight, they will generally be located along roads.[42] Missions for antiaircraft artillery at night include the destruction of enemy illumination means which illuminate Soviet troop

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[39]Betit, P. 27.

[40]LTC M. Mozharov and MAJ B. Krupenin, Combined Training with a Battery at Night, Military Herald, February 1971, P. 53.

[41]Betit, P. 27.

[42]Ibid.

[43]Ibid.

concentrations, and the normal protection of troops from enemy air attacks.[43]

In general, Soviet artillery usage during night operations mirrors the daylight use. Notable exceptions, however, are the night attack without artillery preparation fires, and the reluctance to redeploy artillery cross-country at night.

COMBAT SUPPORT AND SERVICE SUPPORT DURING NIGHT OPERATIONS. Most combat support units, such as engineers and chemical units, are attached directly to motorized rifle companies for night operations. This decentralization of control allows for maximum flexibility of support.

Engineer missions during night operations include reconnaissance (sappers), clearing of minefields, removal of obstacles, assisting in water crossings, emplacement of minefields, and demolition of prominent terrain features which may assist enemy orientation.[44] Although some engineer units do possess night vision devices, it is still probably necessary to illuminate the battlefield in order for them to accomplish some of the above mentioned missions.

Prior to a night assault, engineer observation and listening posts, manned by sapper linguists, will be established forward of each motorized rifle battalion. These linguists will attempt to gain combat intelligence on the opposing forces.[45] During the artillery preparation which precedes the assault, sappers will clear and mark paths

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[43]Betit, P. 27.

[44]Ibid.

[45]Ibid.

through minefields. This is usually accomplished using demolitions or roller-equipped tanks. The cleared lanes are usually six to eight meters wide.[46]

Chemical elements may be attached to each rifle company or platoon. Although the Soviets prefer to decontaminate equipment in special processing points, these elements can provide a limited decontamination capability. The "special processing points" are normally located near inhabited areas since a certain amount of illumination is unavoidable to complete the procedure.[47] In all cases, these points are near frontline troops and close to roads.

The Soviets devote considerable attention to logistics and the planning for supply and resupply of forces conducting night operations. Soviet writings reveal that requirements for night operations increase by 15 to 30 percent over daytime supply rates. Artillery units supporting night operations are normally supplied one or two days in advance. Motorized rifle units are provided more ammunition than normal and each company may have one APC designated to carry the additional load.[48]

Medical evacuation is extremely difficult at night, however, it is the system preferred by the Soviets and their doctrine calls for the evacuation of wounded troops during the cover of darkness. Heavy or mass casualties could over-

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[46] Betit, P. 27.

[47] Ibid, P. 28.

[48] Ibid, P. 29.

whelm the Soviet medical system which continues to rely on truck ambulances, trained dogs used to locate wounded, and limited air ambulance capabilities.[49]

Command and control of night operations is made more difficult by the Soviet doctrine of radio silence or limited radio use. Whenever possible, Soviet commanders will locate themselves as close as possible to the center front of their forces in order to maintain an awareness of the tactical situation. The Soviets view planning and adherence to orders as being a beneficial tradeoff for lack of communications and the threat of electronic warfare measures against them. Still, this does not deter individual initiative on the part of Soviet commanders at night, and unique measures have been taken to insure control and direction. In one such case, forward tanks and APCs were directed to switch on their tail-lights momentarily so that the commander could get a battle-field frontline trace.[50]

Whenever possible, Soviet commanders prefer to lay communications wire between units instead of relying on radio communications. This task becomes extremely difficult at night, and the time required to lay cable is roughly doubled under darkness conditions.[51]

The Soviets have a great appreciation for the strain and tiring effects unique to night operations. Because of

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[49]Betit, P. 30.

[50]Ibid.

[51]Ibid.

this, operational plans include the provision for replacement units from reserves and second echelons to continue the assault at dawn or whenever the situation dictates.[52] This doctrine of continuous, relentless attack makes the night attack all the more important in Soviet planning since it denies the enemy the respite following daylight attacks and can also serve as a hindrance in preparation for subsequent daylight operations.

DEFENSIVE OPERATIONS. Although almost all of the Soviet writings concerning night operations address only the offense, the Soviets do have an appreciation and therefore a tactic for night defensive operations. Historically, as was explained in Chapter II, the Soviets have used the night defense to resupply, reinforce and conduct spoiling counter-attacks. The night defense allows a smaller force, familiar with the terrain and concealed by darkness, to engage and disrupt an enemy's operations.

As stated earlier, command and control of night operations is extremely difficult. When in a defensive position, the Soviets make use of pre-positioned units, wire communications, and more centralized control to try and eliminate some of the command and control problems. The use of illumination is considered as important in the defense as in the offense, and the Soviets employ illumination on the forward edge of the battle area at irregular intervals to detect

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[52] Betit, P. 30.

[53] Ibid.

enemy movements.[53]

During night defensive situations, reserve and second echelon units will be positioned close to the front line so that they can rapidly deploy to positions or cover gaps in defensive lines.[54]

The motorized rifle unit, reinforced with tanks, represents the most common Soviet night defensive formation. Defensive positions are prepared during daylight hours, with each machinegunner, grenadier, and rifleman preparing his own fields of fire. Tanks are normally placed in hull defilade, with predesignated relocation points and withdrawal routes prepared.[55]

The Soviets make extensive use of patrolling and listening and observation posts while in defensive posture. Artillery units plan fires on likely avenues of advance and are equipped with extra illumination rounds. Engineers are used to provide camouflage, construct fortifications, and lay minefields.[56] In all, the Soviet night defense is as well planned and rehearsed as the night offensive. Perhaps the major difference between night offensive and defensive formations is the use of a rather heavy reserve, perhaps a company reinforced in each battalion, to launch counterattacks from the defensive position and steal the initiative from the enemy. The Soviets do not like the defense and will

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[53]Betit, P. 30.

[54]Ibid.

[55]Ibid, P. 32.

[56]Ibid.

make every opportunity to gain the offensive, even at night.

CHAPTER V

CONCLUSIONS

The objective of this thesis was to document historical and contemporary facts on Soviet night operations. From this documentation several conclusions can be drawn about the emphasis the Soviets place on night operations, their ability to conduct them, and the likelihood they will employ night operations in any future conflict.

I have chosen to present these conclusions in the form of answers to hypothetical Essential Elements of Information (EEI) as they might be posed to an intelligence officer by his commander. The answers to these questions, coupled with supporting statements, constitute the essense of the findings in this thesis.

EEI:

1. Will the Soviets conduct night operations in any future conflict?
2. Where will they conduct night operations?
3. When will they conduct night operations?
4. In what strength will they conduct night operations?

WILL THE SOVIETS CONDUCT NIGHT OPERATIONS? Yes. This response is based on the analysis of four factors: the Soviets' history of night operations, their current tactical doctrine, their capabilities, and their intentions. Historically, as documented in Chapter II, the Soviets used night operations extensively in World War II. The tactics of night re-supply and reinforcement were perfected by the Soviets while on the defensive at Stalingrad. Once on the offensive, the Soviets used night attacks to achieve surprise, as at the Battle of Kiev, and to shock the enemy, as at the Battle of Berlin. They employed illumination to guide their forces and to reveal the enemy, and they revealed new weapons at night in order to guard their secrecy.

Current doctrine reveals a continuation of the tactics of surprise and shock. Likewise, the Soviets embrace the offensive assault and relentless pursuit as the very core of their strategy. Current writings reveal that the Soviets adhere to the practice of night re-supply and medical evacuation of wounded. All these factors are evidenced in the vast number of writings devoted to night operations and tactics.

Capability can be addressed in terms of equipments, weapons, and the ability of the soldier to use them. In this respect, the Soviets are indeed capable of conducting night operations. Their night operational equipment, as examined in Chapter III, is highly sophisticated and readily available. The Soviets have devoted considerable amounts of research and

development resources to create usable and reliable navigational aids for their tracked vehicles, weapon sites for individual and crew-served weapons, and light-enhancing equipment for all ground force elements. Their tanks are equipped with illumination ammunition and searchlights, and all command vehicles have topographic navigational gear.

The training programs of the Soviets are perhaps the greatest measure of their night operational capability. The individual Soviet soldier is trained for night combat, as are all units from squad to regimental size. One source estimates that fully 40% of all individual and unit training is devoted to night operations.[1]

If we can conclude that the Soviets have a history of night operations, that their current doctrine includes night operational techniques, and that they appear capable of conducting such operations, then we can address their intentions with a degree of assurance. Any army or unit that attempts to conduct combat in any manner other than the way it has trained will most likely be unsuccessful. The Soviets train extensively for night operations, therefore it can be deduced that they plan to fight at night. When this is coupled with the fact that they have spent great quantities of money and time to create state-of-the-art equipments for night combat, the conclusion becomes even clearer. Yes.

[1]DDI-1100-128-76, p VIII-1.

WHEN WILL THE SOVIETS CONDUCT NIGHT OPERATIONS?

The "when" in this question does not equate to a particular day, but is associated with the most likely times during a battle or campaign that the Soviets will conduct night operations. An examination of the information presented in Chapter IV reveals that there are perhaps two times that the Soviets favor most: as a continuation of a successful daylight assault, or as a prelude to an intensive daylight attack.

In the case of the first instance, the Soviets will continue a successful daylight attack by inserting new units into the battle that are equipped for night combat, maintaining their momentum without a break in the action. When employing night operations as a prelude to subsequent daylight assaults, the Soviets will plan extensively, and may even rehearse the action several times prior to the attack. The planning involves a reconnaissance of the area to be assaulted. Here, the Soviets favor conducting the reconnaissance during the late afternoon hours and attacking after dusk rather than trying to conduct the recon during darkness and attacking before dawn.

While we can conclude that the Soviets prefer to conduct night operations under certain conditions that they have control of and at certain stages of a battle or campaign, we must also conclude that they will conduct night operations at any time they feel they are needed or will contribute to the overall success of the operation.

WHERE WILL THE SOVIETS CONDUCT NIGHT OPERATIONS?

During World War II, the Soviets conducted major night operations in built up areas such as Stalingrad and Berlin. They attacked across rivers, at Stalingrad and at Kiev, and they assaulted encircled German units on the open Steppes. It could be said that the Soviets used the night attack everywhere it was needed. An examination of current Soviet doctrine reveals some profound information about where the Soviets may conduct night attacks in future conflicts.

As stated in Chapter IV, the Soviets do not consider the crossing of rivers or other water obstacles at night to be of any greater significance than a daylight crossing. Likewise, the breaching of minefields at night is considered a normal tactic. The Soviets feel that they can conduct effective night assaults almost anywhere they can fight during the daytime. Their writings reveal that they prefer to employ smaller sized attacks against weak points in an enemy's defenses, and on occasion, where least expected, such as through a minefield.

Their use of the night march formation and their column composition indicates that they are willing to conduct a meeting engagement at night, as eagerly as they pursue the same tactic during the day. The night attack can be expected to adhere to the Soviet principle of exploitation of success rather than reinforcement of units meeting the stiffest resistance. We can expect the Soviets to attack at night where they anticipate the least force resistance or where

they anticipate achieving the greatest surprise, even if this means crossing a river or breaching a minefield to reach the enemy.

Other factors in the "where" equation relate to the Soviet use of reconnaissance and security at night and the positioning of command elements, reserves, and second echelon forces. As stated in Chapter IV, front and rear security elements for a unit on the move at night will maintain approximately half the daytime distance from the main body of the force. Likewise, flank security and reserve and second echelon forces will be positioned closer to the main body. When resting during night marches, Soviet units can be expected to withdraw to a position one to two kilometers off the march route and parallel to it. The march formation and unit order will remain the same during the rest.

Because of the difficulty of cross-country movement at night, towed and self-propelled artillery units can be expected to remain close to roads, leapfroging forward as the attack progresses. Command elements will remain close to roads or supply routes so that commanders can deploy quickly to key areas of the attack. Soviet tank forces, especially those armor forces attached to motorized units, can be expected to make more use of the overwatch position during night operations.

In general then, we can anticipate that the Soviets will adhere to certain principles of their operational art which apply to daylight operations: exploitation of success

by reserves and second echelon forces, relentless assault and massing against weak points and attacks in echelon. On the other hand, the Soviets appear to allow more flexibility during night operations and are likely to attempt less conventional formations or less predictable tactics. They may attack where they would not during daytime, such as across obstacles and through minefields.

IN WHAT STRENGTH WILL THE SOVIETS CONDUCT NIGHT OPERATIONS? Soviet writings reveal that the Soviets train for night operations using all sized units from company to combined arms army. During World War II they conducted the night attack against Berlin with an entire Front formation. Conclusions regarding the size of forces most likely to be involved in night operations are drawn based on training accounts and doctrinal procedures.

The smallest unit which might conduct an independent night attack appears to be the motorized rifle or tank company, supported by an attached artillery battery. The most common force conducting independent operations at night is the motorized rifle or tank battalion, supported by a battalion of attached artillery and engineer elements. It appears that the Soviets may use such an attack to support or precede a division-sized operation.

When a motorized rifle battalion attacks at night, the supporting artillery is usually decentralized, with a battery being attached to each motorized company. The battalion will attack with three companies on line, with a reinforced platoon following as the battalion reserve. If

tanks are attached, they may lead the dismounted infantry or take up overwatch positions and serve as a rather static fire support system for APC mounted forces. The normal battalion front will decrease from the daylight attack frontage of one-and-a-half or two kilometers to as narrow as one kilometer if the infantry remains mounted. If the infantry is dismounted, this frontage could widen up to 400 meters for each platoon, giving the unit a much larger front than during daylight operations.

When the tank battalion attacks at night, the commander will normally assign a different avenue of assault for each company, thus having a three-pronged attack. Some units may deploy an overwatch company for fire against anti-tank forces. As with the motorized battalion, the artillery supporting the tank battalion assault will be decentralized for attachment to each assaulting company.

The overriding principle behind the size of the unit the Soviets will use at night is the mission of the parent unit in subsequent operations. Since the night attack is used to enhance or continue other operations. it is the next mission of the unit that will determine the size of the night force and the support given to it.

GENERAL CONCLUSIONS. The Soviets will fight at night. That is the basic conclusion that can be drawn from this research. Other conclusions which have meaning within the scope and limitations of this thesis are as follows: The Soviet soldier and his unit are well trained for night combat.

The Soviets write extensively about how they conduct their night training, and they review lessons learned from actual combat during World War II and from training experiences. The Soviets have expended considerable resources to develop modern, efficient night equipments. Their night sighting devices, radars, and navigational aids are excellent.

The Soviet commander apparently has greater flexibility at night than during daylight operations. He is responsible for his own reconnaissance and planning, and he is allowed to develop his plan given the situation and not a set of rules. Historical accounts reveal that initiative has played a part in Soviet night operations and that this initiative is incouraged. Whether it be a counterattack at night by weary soldiers at Stalingrad or a cat-and-mouse armor ruse, Soviet commanders have shown that they can think for themselves and are allowed to do so. The Soviets, for all their apparent inflexibility, recognize the importance of the physical and psychological advantages of darkness conditions and they are trained to make use of them.

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BLACK NITE FLARE

NWSC/CR/RDTR-39
2 September 1976

Carl W. Lohkamp
Operations Research Division
Applied Sciences Department

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The Army and the Navy have and are using image intensifiers and low light level televisions (LLLTV). These items are used at all levels, that is, from individual soldier in the Army to part of the fire control directorate for the TARTAR missile system in the Navy. These electro-optical (EO) devices, however fail to perform adequately under 1/4 moon or less natural illumination conditions. → over

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20. The EO image intensifiers and LLLTV devices which are now in or are soon to be in service utilize the S-1, improved S-20, or the S-25 photoemitter surfaces. Examination of these responses shows that the performance of the EO devices can be enhanced by visible and near infrared flux. Discussion of several compositions having peak emissions in the near infrared portion of the spectrum is included as well as reflectance data on natural terrain.

Testing of these compositions in the laboratory as well as in the field has been completed. Flare output data for the visible and infrared portion of the spectrum is included in the report.

Black Nite Flare

The services are using low light level televisions (LLLTV) tripod mounted image intensifiers, hand held and rifle mounted units, and goggle type devices. Image intensifiers are used at all authority levels and in all locations such as the B-52 bomber, the individual foot soldier and the TARTAR fire control system.

All image intensifiers rely on intensifying the image flux that is present to gain a usable image. Present day intensifiers do not perform adequately under one-quarter moonlight or less natural illumination conditions. Examination of the lunar cycle and cloud cover data reveals that in approximately 73% of the night hours you have one quarter moonlight or less natural illumination (1). To enhance the image produced by the intensifier and LLLTV, several techniques have been employed. These include: (a) use of visible illuminating flares; (b) use of spotlights filtered to remove the visible flux and transmit the near infrared flux; (c) use of laser illuminators; (d) use of a pyrotechnic flare having primarily near infrared emission (2).

Examine the disadvantages of the first three techniques of enhancement. Visible flares do enhance the performance of the system (3); however, they also allow all friendly and enemy forces to see. Drift of the visible flare can lead to exposure of friendly positions. Use of spotlights filtered to remove the visible flux is a technique used in the past, particularly on armored vehicles. This technique has one large drawback which is: if the enemy has night vision equipment, he can see exactly where the searchlight is and can direct his fire to destroy it and the carrying vehicle. The third technique of laser augmentation of the imaging system is presently being explored by at least the Navy and the Air Force. The major drawback is similar to the spotlight in that you give away your position when you activate your laser if the opposing forces have image intensifiers. An additional problem that is encountered is the need of pulse gating the systems such that the flux scattered in the laser beam in the intervening atmosphere between the source and the target being illuminated does not obscure the target.

The semi-convert near-infrared flare overcomes many of these problems; however, there are some drawbacks to using this type of flare also. Drawbacks to the infrared flare include having some visible candlepower and it is nearly impossible to deploy a flare without generating some acoustic signature.

To determine what types of near-infrared flares are desirable, examination of the spectral responsivity of the photoemitters is in order. Figure 1 is a plot of three of the more widely found surfaces in image intensifiers today. The S-1 photoemitter is found in the Metascope and many of the older devices and is usually used for visual tasks that are of short range. The S-20 surface was found in some of the older Starlight scopes. Newer Starlight scopes have an improved S-20 response which is closer to the S-25 response. The PVS-5 night goggles have a response closely approximated by that shown as the S-25 response.

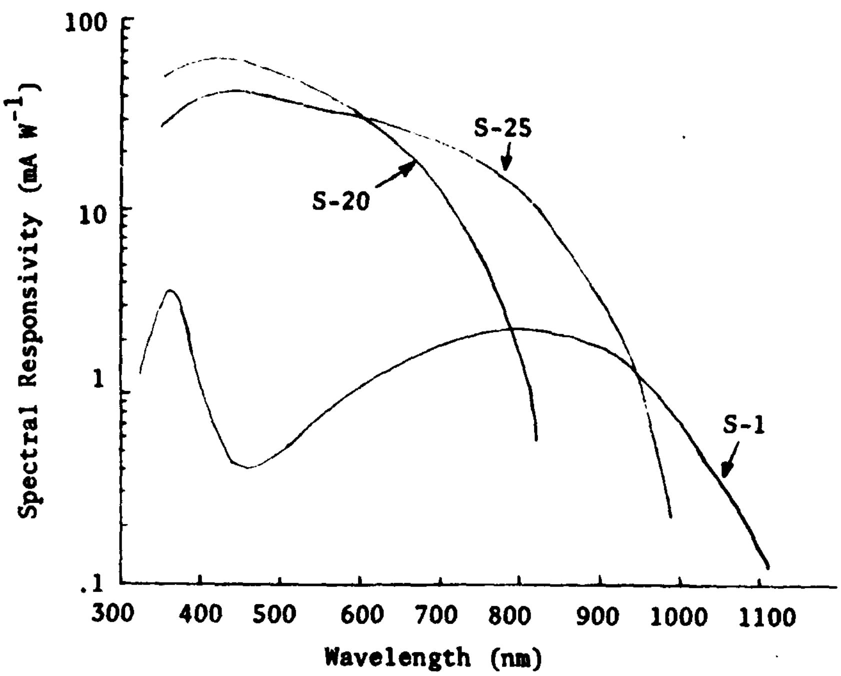

Figure 1. Visible and Near IR Photoemitter Characteristics.

With these responses in mind, we have obtained three types of compositions which have potential as sources. These compositions utilize alkali metal nitrates. They are potassium nitrate, rubidium nitrate and cesium nitrate. Figure 2 is the atomic line emission spectra (4) of the mentioned alkali metals.

Potassium having resonance line emission at .7698 and .7644 microns mates very well with the S-20 and S-25 responses shown in Figure 1, yet is just outside the visible spectrum which can be defined as .4 - .74 micron (y = .0001 at .760 micron). Broadening of these line emissions coupled with very limited eye response at .76 micron does give some visible flux. There is, of course, some flux in the visible due to other line emission and the temperature of the reaction.

In an attempt to reduce the visible emission and have the emission a bit farther in the infrared, rubidium nitrate was utilized as an oxidizer. The emissions near .79 micron mate reasonably well with the S-1 and S-25 curves. The general problem, however, is that there is a greater number of in-service image intensifiers having response properties between the S-20 and the S-25 curves than the S-25 to S-1 portion of the spectrum.

To obtain flux that is optimally compatible with the S-1 surface, cesium nitrate was utilized as an oxidizer in several flare formulations. Due to the temperature of the reaction, burn rates experienced in flare formulations, and atomic spectra, these flares had large IR power output; however, they also had greater visible flux emitted.

Typical formulations tested of all three types are shown in Table 1.

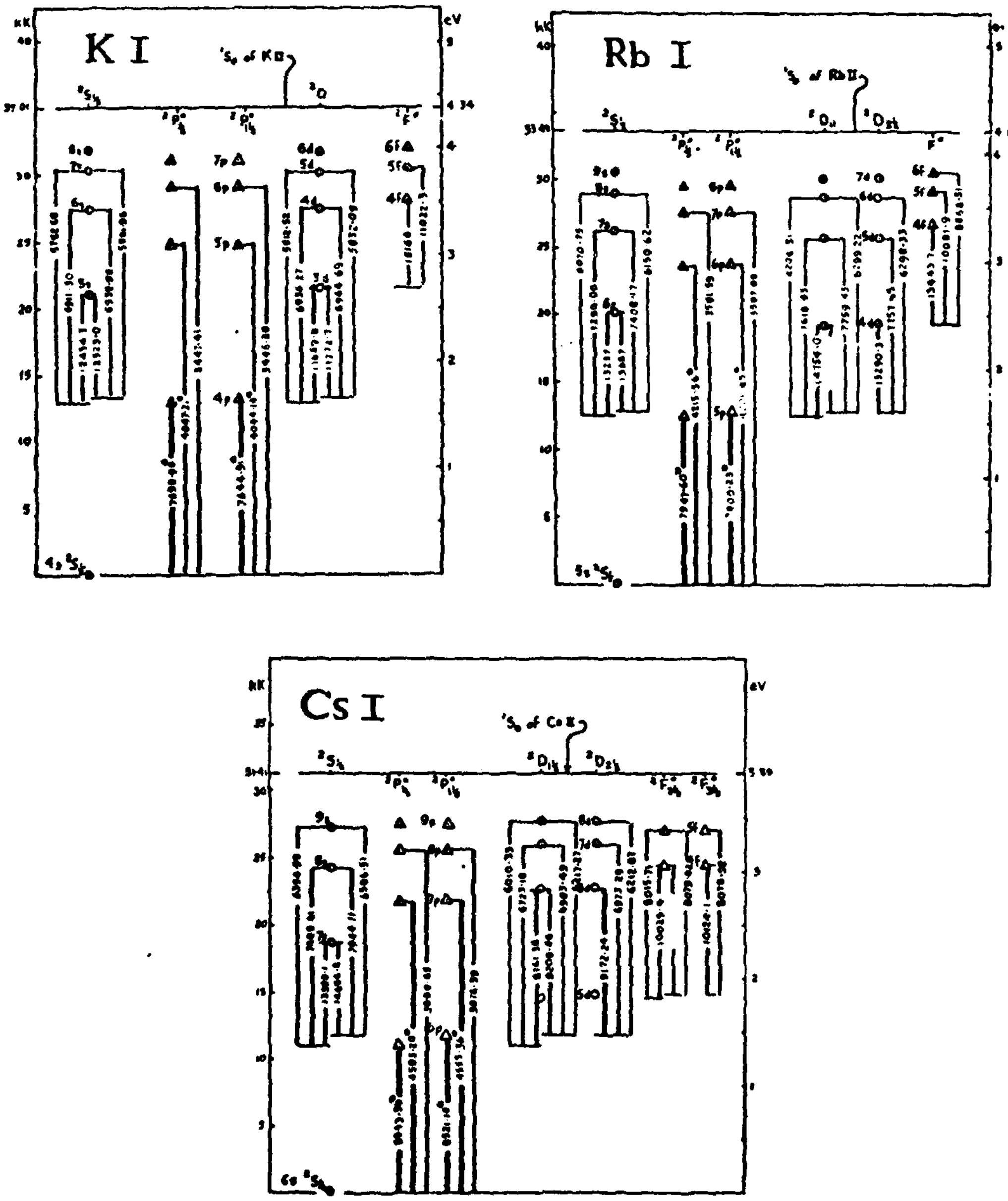

Figure 2. Atomic Spectra (taken from Candler)

Table I. Flare Formulas

	.76 Micron flare	.79 Micron flare	.8-.9 Micron flare
Silicon	10	10	16.3
Potassium nitrate	70		
Cesium nitrate			78.7
Rubidium nitrate		60.8	
Hexamethylenetetromine	16	23.2	
Epoxy resin (DER 321)	2.8	4.2	3.3
Epoxy hardener (DEH 14)	1.2	1.8	1.7

Flare candles composed of these compositions have been pressed into paper tubes having diameters from 1.6" to 4". Radiometric and spectra data on the potassium, which is the most interesting to NAVSEA and NAVAIR applications, have been taken. Table II contains a summary of data of primary interest to the design agents.

Table II. Flare Performance

	Watts/Steradian (.7-1 Micron)	Candlepower (.4-.74 Micron)	Burn rate (sec/in)
40 MM	14	65	45
MK 45 size (4.25")	160	900	45
*EX-18 size (3.375")	85	600	45
**155 MM size	80-100	600	40

* Candle composition pressed into the 5" EX-18 projectile paper.
** Pressed in steel containers that are used for the 155 MM illuminating load.

An interesting point noted during experimentation with the 40 MM size is that 20-30% of the visible flux originates from the burning of the paper tube on the flare candle. A large part of this flux is from the sodium impurity found in the paper. The spectral data taken on the near infrared flares shows that a predominant portion of the flux in the near infrared originates from the resonance lines. The visible emission is primarily composed of the gray body emission due to temperature and to the sodium impurity in the ingredients. A lesser amount of flux originates from the atomic lines in the visible spectrum.

One portion of the problems left unaddressed is that of the reflective properties of the elements in the natural scenario. Figures 3 and 4, although representing only a few materials formed in the battlefield, do indicate a general pattern. Most items are more reflective in the near infrared than in the visible.

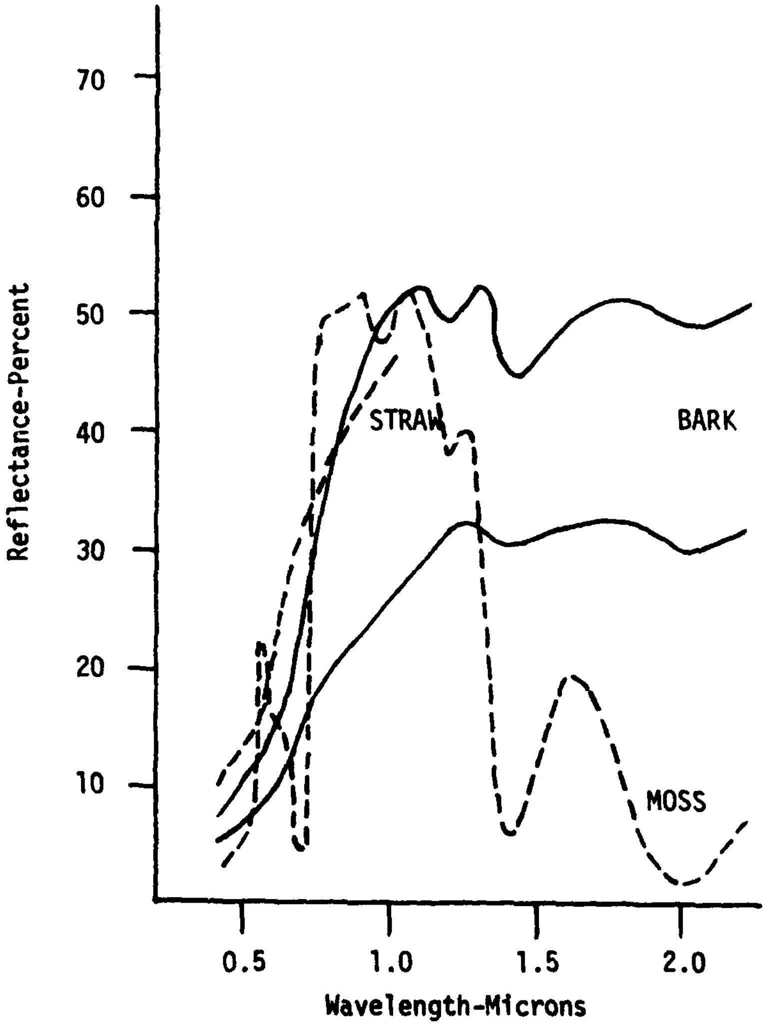

FIGURE 3

SPECTRAL REFLECTANCE OF TYPICAL EXAMPLES OF MOSS, TREE BARK, AND DRY STRAW

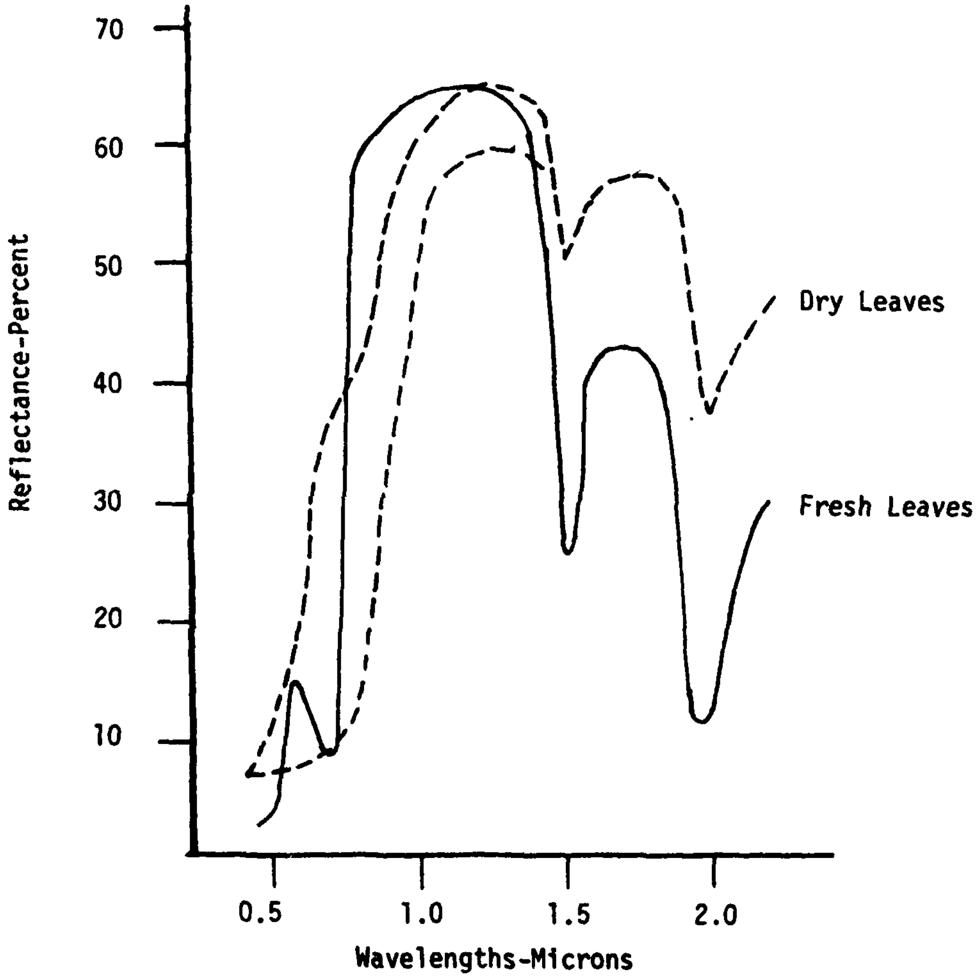

FIGURE 4

SPECTRAL REFLECTANCE OF TYPICAL LEAVES OF DECIDUOUS TREES

A video tape of the performance of image intensifiers under conditions of starlight, with visible flares and with near-infrared (EX-18 size) potassium flares, has been obtained. This tape, shown at the 5th International Pyrotechnic Seminar, demonstrates the vast improvement in target detection capability that can be obtained with the flares. The performance through the scope is comparable when utilizing visible and infrared flares. The visible flares fully illuminate, to the naked eye, everyone in the total test area while only those having night vision devices were capable of utilizing the flux from the IR flares.

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6

Digitizing the Parthenon: Estimating Surface Reflectance under Measured Natural Illumination

Paul Debevec, Chris Tchou, Andrew Gardner, Tim Hawkins, Charis Poullis, Jessi Stumpfel, Andrew Jones, Nathaniel Yun, Per Einarsson, Therese Lundgren, Marcos Fajardo

University of Southern California
Email: debevec@ict.usc.edu, tchouster@gmail.com, androo.gardner@gmail.com, tim@lightstage.com, charalambos@poullis.org, jessi@cs.caltech.edu, jones@ict.usc.edu, corellian_knight@hotmail.com, per.einarsson@dice.se, therese.lundgren@gmail.com, marcosss@gmail.com

Philippe Martinez

Ecole Normale Superieure
Email: pmartine@ens.fr

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6.1 Introduction

Digitizing objects and environments from the real world has become an important part of creating realistic computer graphics. Capturing geometric models has become a common process through the use of structured lighting, laser triangulation, and laser time-of-flight measurements. Recent projects such as [1–3] have shown that accurate and detailed geometric models can be acquired of real-world objects using these techniques.

To produce renderings of an object under changing lighting as well as viewpoint, it is necessary to digitize not only the object's geometry but also its reflectance properties: how each point of the object reflects light. Digitizing reflectance properties has proven to be a complex problem, since these properties can vary across the surface of an object, and since the reflectance properties of even a single surface point can be complicated to express and measure. Some of the best results that have been obtained [2, 4, 5] capture digital photographs of objects from a variety of viewing and illumination directions, and from these measurements estimate reflectance model parameters for each surface point.

Digitizing the reflectance properties of outdoor scenes can be more complicated than for objects since it is more difficult to control the illumination and viewpoints of the surfaces. Surfaces are most easily photographed from ground level rather than from a full range of angles. During the daytime the illumination conditions in an environment change continuously. Finally, outdoor scenes generally exhibit significant mutual illumination between their surfaces, which must be accounted for in the reflectance estimation process. Two recent pieces of work have made important inroads into this problem. In Yu at al. [6] estimated spatially varying reflectance properties of an outdoor building based on fitting observations of the incident illumination to a sky model, and [7] estimated reflectance properties of a room interior based on known light source positions and using a finite element radiosity technique to take surface interreflections into account.

In this paper, we describe a process that synthesizes previous results for digitizing geometry and reflectance and extends them to the context of digitizing a complex real-world scene observed under arbitrary natural illumination. The data we acquire includes a geometric model of the scene obtained through laser scanning, a set of photographs of the scene under various natural illumination conditions, a corresponding set of measurements of the incident illumination for each photograph, and finally, a small set of Bi-directional Reflectance Distribution Function (BRDF) measurements of representative surfaces within the scene. To estimate the scene's reflectance properties, we use a global illumination algorithm to render the model from each of the photographed viewpoints as illuminated by the corresponding incident illumination measurements. We compare these renderings to the photographs, and then iteratively update the surface reflectance properties to best correspond to the scene's appearance in the photographs. Full BRDFs for the scene's surfaces are inferred from the measured BRDF samples. The result is a set of estimated reflectance properties for each point in the scene that most closely generates the scene's appearance under all input illumination conditions.

While the process we describe leverages existing techniques, our work includes several novel contributions. These include our incident illumination measurement process, which can measure the full dynamic range of both sunlit and cloudy natural illumination conditions, a hand-held BRDF measurement process suitable for use in the field, and an iterative multiresolution inverse global illumination process capable of estimating surface reflectance properties from multiple images for scenes with complex geometry seen under complex incident illumination.

The scene we digitize is the Parthenon in Athens, Greece, digitally laser scanned and photographed in April 2003 in collaboration with the ongoing Acropolis Restoration project. Scaffolding and equipment around the structure prevented the application of the process to the middle section of the temple, but we were able to derive models and reflectance parameters for both the East and West facades. We validated the accuracy of our results by comparing our reflectance measurements to ground truth measurements of specific surfaces around the site, and we generate renderings of the model under novel lighting that are consistent with real photographs of the site. At the end of the paper we discuss avenues for future work to increase the generality of these techniques. The work in this chapter was first described as a Technical Report in [8].

6.2 Background and Related Work

The process we present leverages previous results in 3D scanning, reflectance modeling, lighting recovery, and reflectometry of objects and environments. Techniques for building 3D models from multiple range scans generally involve first aligning the scans to each other [9,10], and then combining the scans into a consistent geometric model by either "zippering" the overlapping meshes [11] or using volumetric merging [12] to create a new geometric mesh that optimizes its proximity to all of the available scans. In its simplest form, a point's reflectance properties can be expressed in terms of its Lambertian surface color - usually an RGB triplet expressing the point's red, green, and blue reflectance properties. More complex reflectance models can include parametric models of specular and retroflective components; some commonly used models are [13–15]. More generally, a point's reflectance can be characterized in terms of its Bi-directional Reflectance Distribution Function (BRDF) [16], which is a 4D function that characterizes for each incident illumination direction the complete distribution of reflected illumination. Marschner et al. [17] proposed an efficient method for measuring a material's BRDFs if a convex homogeneous sample is available. Recent work has proposed models which also consider scattering of illumination within translucent materials [18]. To estimate a scene's reflectance properties, we use an incident illumination measurement process. Marschner et al. [19] recovered low-resolution incident illumination conditions by observing an object with known geometry and reflectance properties. Sato et al. [20] estimated incident illumination conditions by observing the shadows cast from objects with known geometry. Debevec in [21] acquired high-resolution lighting environments by taking high dynamic range images [22] of a mirrored sphere, but did not recover natural illumination environments where the sun was directly visible. We combine ideas from [19, 21] to record high-resolution incident illumination conditions in cloudy, partly cloudy, and sunlit environments. Considerable recent work has presented techniques to measure spatially-varying reflectance properties of objects. Marschner in [4] uses photographs of a 3D scanned object taken under point-light source illumination to estimate its spatially varying diffuse albedo. This work used a texture atlas system to store the surface colors of arbitrarily complex geometry, which we also perform in our work. The work assumed that the object was Lambertian, and only considered local reflections of the illumination. Sato et al. [23] use a similar sort of dataset to compute a spatially-varying diffuse component and a sparsely sampled specular component of an object. Rushmeier et al. [2] use a photometric stereo technique [24, 25] to estimate spatially varying Lambertian color as well as improved surface normals for the geometry. Rocchini et al. [26] use this technique to compute diffuse texture maps for 3D scanned objects from multiple images. Debevec et al. [27] use a dense set of illumination directions to estimate spatially-varying diffuse and specular parameters and surface normals. Lensch et al. [5] presents an advanced technique for recovering spatially-varying BRDFs of real-world objects, performing principal component analysis of relatively sparse lighting and viewing directions to cluster the object's surfaces into patches of similar reflectance. In this way, many reflectance observations of the object as a whole are used to estimate spatially-varying BRDF models for surfaces seen from limited viewing and lighting directions. Our reflectance modeling technique is less general, but adapts ideas from this work to estimate spatially-varying non-Lambertian reflectance properties of outdoor scenes observed under natural illumination conditions, and we also account for mutual illumination. Capturing the reflectance properties of surfaces in large-scale environments can be more complex, since it can be harder to control the lighting conditions on the surfaces and the viewpoints from which they are photographed. Yu et al. [6] solve for the reflectance properties of a polygonal model of an outdoor scene modeled with photogrammetry. The technique used photographs taken under clear sky conditions, fitting a small number of radiance measurements to a parameterized sky model. The process estimated spatially varying diffuse and piecewise constant specular parameters, but did not consider retroreflective components. The process derived two *pseudo-BRDFs* for each surface, one

according to its reflectance of light from the sun and one according to its reflectance of light from the sky and environment. This allowed more general spectral modeling but required every surface to be observed under direct sunlight in at least one photograph, which we do not require. Using room interiors [7, 28, 29] estimate spatially varying diffuse and piecewise constant specular parameters using inverse global illumination. The techniques used knowledge of the position and intensity of the scene's light sources, using global illumination to account for the mutual illumination between the scene's surfaces. Our work combines and extends aspects of each of these techniques: we use pictures of our scene under natural illumination conditions, but we image the illumination directly in order to use photographs taken in sunny, partly sunny, or cloudy conditions. We infer non-Lambertian reflectance from sampled surface BRDFs. We do not consider full-spectral reflectance, but have found RGB imaging to be sufficiently accurate for the natural illumination and reflectance properties recorded in this work. We provide comparisons to ground truth reflectance for several surfaces within the scene. Finally, we use a more general Monte-Carlo global illumination algorithm to perform our inverse rendering, and we employ a multiresolution geometry technique to efficiently process a complex laser-scanned model.

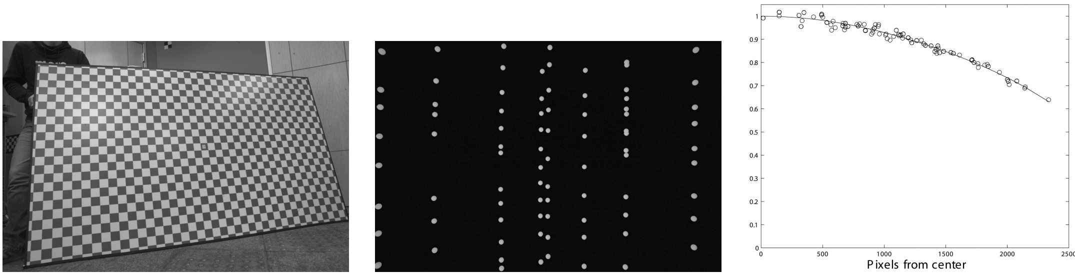
6.3 Data Acquisiton and Calibration

6.3.1 Camera Calibration

In this work we used a Canon EOS D30 and a Canon EOS 1Ds digital camera, which were calibrated geometrically and radiometrically. For geometric calibration, we used the Camera Calibration Toolbox for Matlab [30] which uses techniques from [31]. Since changing the focus of a lens usually changes its focal length, we calibrated our lenses at chosen fixed focal lengths. The main lens used for photographing the environment was a 24mm lens focused at infinity. Since a small calibration object held near this lens would be out of focus, we built a larger calibration object 1.2m $\times$ 2.1m from an aluminum honeycomb panel with a 5cm square checkerboard pattern applied (Figure 6.1(a)). Though nearly all images were acquired at $f/8$ aperture, we verified that the camera intrinsic parameters varied insignificantly (less than 0.05%) with changes of $f/stop$ from $f/2.8$ to $f/22$. In this work we wished to obtain radiometrically linear pixel values that would be consistent for images taken with different cameras, lenses, shutter speeds, and $f/stop$. We verified that the "RAW" 12-bit data from the cameras was linear using three methods: we photographed a gray scale calibration chart, we used the radiometric self-calibration technique of [22], and we verified that pixel values were proportional to exposure times for a static scene. From this we found that the RAW pixel values exhibited linear response to within 0.1% for values up to 3,000 out of 4,095, after which saturation appeared to reduce pixel sensitivity. We ignored values outside of this linear range, and we used multiple exposures to increase the effective dynamic range of the camera when necessary.

Most lenses exhibit a radial intensity falloff, producing dimmer pixel values at the periphery of the image. We mounted each camera on a Kaidan nodal rotation head and photographed a diffuse disk light source at an array of positions for each lens at each $f/stop$ used for data capture (Figure 6.1(b)). From these intensities recorded at different image points, we fit a radially symmetric 6th order even polynomial to model the falloff curve and produce a flat-field response function, normalized to unit response at the image center.

Each digital camera used had minor variations in sensitivity and color response. We calibrated these variations by photographing a MacBeth color checker chart under natural illumination with each camera, lens, and $f/stop$ combination, and solved for the best 3×3 color matrix to convert each image into the same color space. Finally we used a utility for converting RAW images to floating-point images using the EXIF metadata for camera model, lens, ISO, f/stop, and shutter speed



(a) (b) (c)

FIGURE 6.1
(a) 1.2m $\times$ 2.1m geometric calibration object; (b) Lens falloff measurements for 24mm lens at $f/8$; (c) Lens falloff curve for (b).

to apply the appropriate radiometric scaling factors and matrices. These images were organized in a PostGreSQL database for convenient access.

6.3.2 BRDF Measurement and Modeling

In this work we measure BRDFs of a set of representative surface samples, which we use to form the most plausible BRDFs for the rest of the scene. Our relatively simple technique is motivated by the principal component analyses of reflectance properties used in [5, 32], except that we choose our basis BRDFs manually. Choosing the principal BRDFs in this way meant that BRDF data collected under controlled illumination could be taken for a small area of the site, while the large-scale scene could be photographed under a limited set of natural illumination conditions.

Data Collection and Registration

The site used in this work is composed entirely of marble, but its surfaces have been subject to different discoloration processes yielding significant reflectance variations. We located an accessible 30cm $\times$ 30cm surface that exhibited a range of coloration properties representative of the site. Since measuring the reflectance properties of this surface required controlled illumination conditions, we performed these measurements during our limited nighttime access to the site and used a BRDF measurement technique that could be executed quickly.

The BRDF measurement setup (Figure 6.2), includes a hand-held light source and camera, and uses a frame placed around the sample area that allows the lighting and viewing directions to be estimated from the images taken with the camera. The frame contains fiducial markers at each corner of the frame's aperture from which the camera's position can be estimated, and two glossy black plastic spheres used to determine the 3D position of the light source. Finally, the device includes a diffuse white reflectance standard parallel to the sample area for determining the intensity of the light source.

The light source chosen was a 1,000W halogen source mounted in a small diffuser box, held approximately 3m from the surface. Our capture assumed that the surfaces exhibited isotropic reflection, requiring the light source to be moved only within a single plane of incidence. We placed the light source in four consecutive positions of $0°$, $30°$, $50°$, $75°$, and for each took hand-held photographs at a distance of approximately 2m from twenty directions distributed on the incident hemisphere, taking care to sample the specular and retroreflective directions with a greater number of observations. Dark clothing was worn to reduce stray illumination on the sample. The full capture process involving 83 photographs required forty minutes.

Data Analysis and Reflectance Model Fitting

To calculate the viewing and lighting directions, we first determined the position of the camera from the known 3D positions of the four fiducial markers using photogrammetry. With the camera

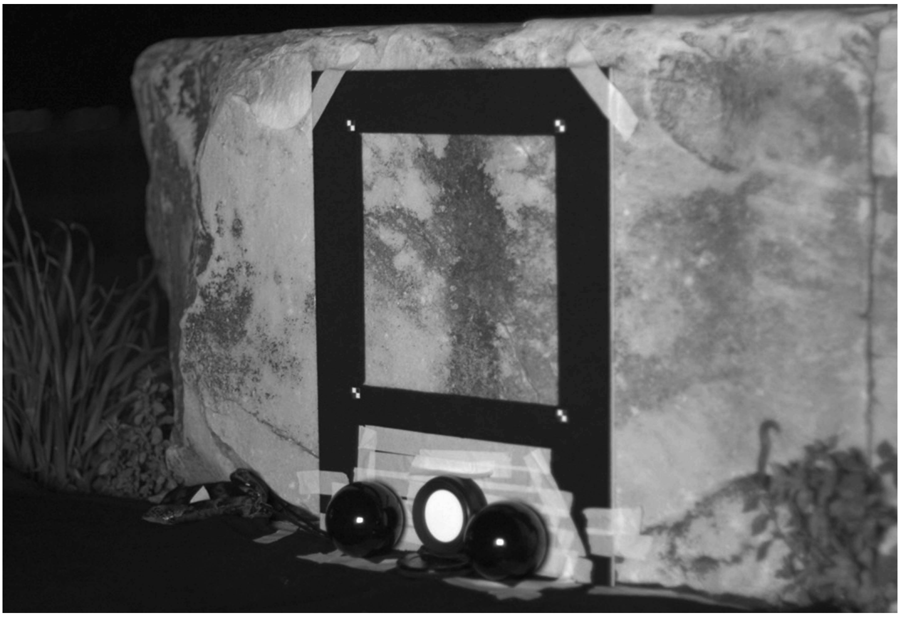


FIGURE 6.2
BRDF samples are measured from a 30cm square region exhibiting a representative set of surface reflectance properties. The technique used a hand-held light source and camera and a calibration frame to acquire the BRDF data quickly.

positions known, we computed the positions of the two spheres by tracing rays from the camera centers through the sphere centers for several photographs, and calculated the intersection points of these rays. With the sphere positions known, we determined each light position by shooting rays toward the center of the light's reflection in the spheres. Reflecting the rays off the spheres, we find the center of the light source position where the two rays most nearly intersect. Similar techniques to derive light source positions have been used in [5, 33].

From the diffuse white reflectance standard, the incoming light source intensity for each image could be determined. By dividing the overall image intensity by the color of the reflectance standard, all images were normalized by the incoming light source intensity. We then chose three different areas within the sampling region best corresponding to the different reflectance properties of the large-scale scene. These properties included a light tan area that is the dominant color of the site's surfaces, a brown color corresponding to encrusted biological material, and a black color representative of soot deposits. To track each of these sampling areas across the dataset, we applied a homography to each image to map them to a consistent orthographic viewpoint. For each sampling area, we then obtained a BRDF sample by selecting a 30×30 pixel region and computing the average RGB value. Had there been a greater variety of reflectance properties in the sample, a PCA analysis of the entire sample area as in [5] could have been used.

Looking at Figure 6.3, the data show largely diffuse reflectance but with noticeable retroreflective and broad specular components. To extrapolate the BRDF samples to a complete BRDF, we fit the BRDF to the Lafortune cosine lobe model (Eq. 6.1) in its isotropic form with three lobes for the Lambertian, specular, and retroreflective components:

$$f(\overrightarrow{u}, \overrightarrow{v}) = \rho_d + \sum_i [C_{xy,i}(u_x v_x + u_y v_y) + C_{z,i} u_z v_z]^{N_i} \quad (6.1)$$

As suggested in [15], we then use a non-linear Levenberg-Marquardt optimization algorithm to

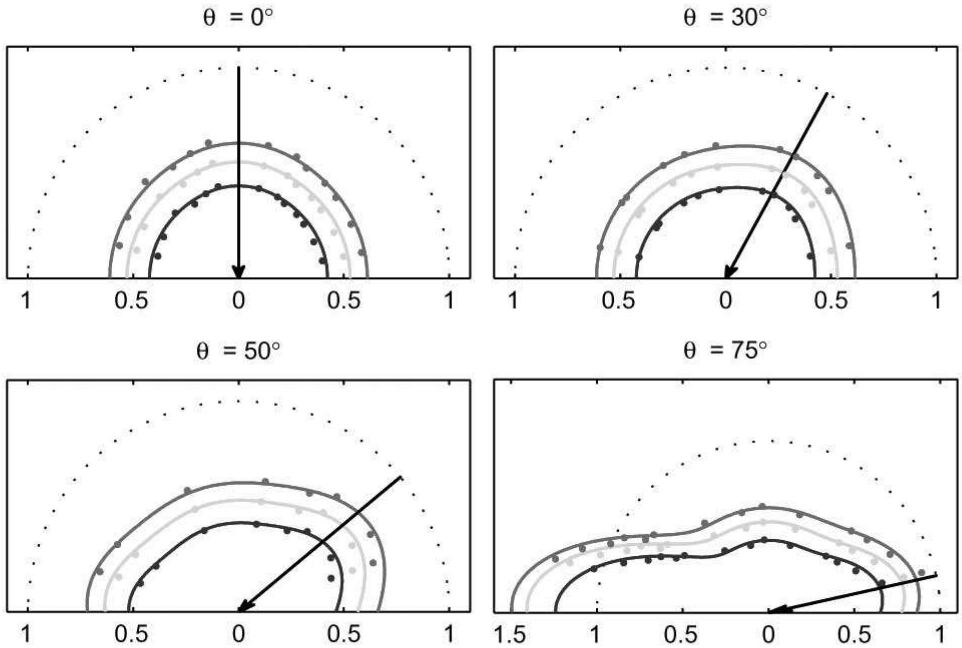


FIGURE 6.3
BRDF data and fitted reflectance lobes are shown for the RGB colors of the tan material sample for the four incident illumination directions. Only measurements within $15°$ of in-plane are plotted.

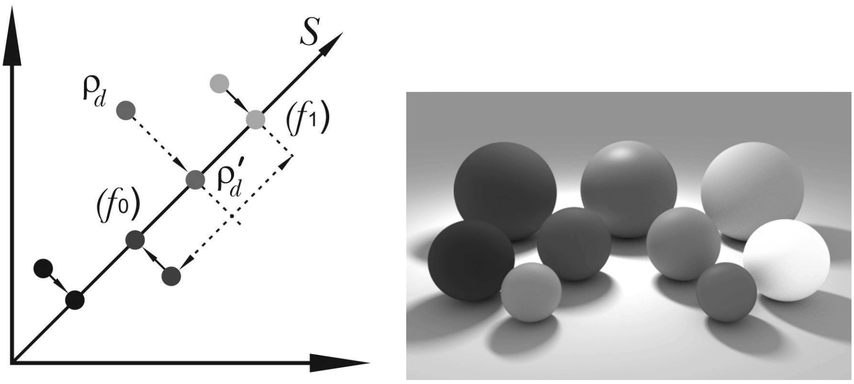
determine the parameters of the model from our measured data. We first estimate the Lambertian component ρ_d, and then fit a retroreflective and a specular lobe separately before optimizing all the parameters in a single system. The resulting BRDFs (Figure 6.4(b), back row) show mostly Lambertian reflectance with noticeable retroreflection and rough specular components at glancing angles. The brown area exhibited the greatest specular reflection, while the black area was the most retroreflective.

BRDF Inference

We wish to be able to make maximal use of the BRDF information obtained from our material samples in estimating the reflectance properties of the rest of the scene. The approach we take is informed by the BRDF basis construction technique from [5], the data-driven reflectance model presented in [32], and spatially-varying BRDF construction technique used in [34]. Because the surfaces of the rest of the scene will often be seen in relatively few photographs under relatively diffuse illumination, the most reliable observation of a surface's reflectance is its Lambertian color. Thus, we form our problem as one of inferring the most plausible BRDF for a surface point given its Lambertian color and the BRDF samples available.

We first perform a principal component analysis of the Lambertian colors of the BRDF samples available. For RGB images, the number of significant eigenvalues will be at most three, and for our samples the first eigenvalue dominates, corresponding to a color vector of (0.688, 0.573, 0.445). We project the Lambertian color of each of our sample BRDFs onto the 1D subspace S (Figure 6.4(a)) formed by this eigenvector. To construct a plausible BRDF f for a surface having a Lambertian color ρ_d, we project ρ_d onto S to obtain the projected color ρ'_d. We then determine the two BRDF samples whose Lambertian components project most closely to ρ'_d. We form a new BRDF f' by linearly interpolating the Lafortune parameters (C_{xy}, C_z, N) of the specular and retroreflective lobes of these two nearest BRDFs f_0 and f_1 based on distance. Finally, since the retroflective color of a

surface usually corresponds closely to its Lambertian color, we adjust the color of the retroflective lobe to correspond to the actual Lambertian color ρ_d rather than the projected color ρ'_d. We do this by dividing the retroreflective parameters C_{xy} and C_z by $(\rho'_d)^{1/N}$ and then multiplying by $(\rho_d)^{1/N}$ for each color channel, which effectively scales the retroreflective lobe to best correspond to the Lambertian color ρ_d. Figure 6.4(b) shows a rendering with several BRDFs inferred from new Lambertian colors with this process.



(a) (b)

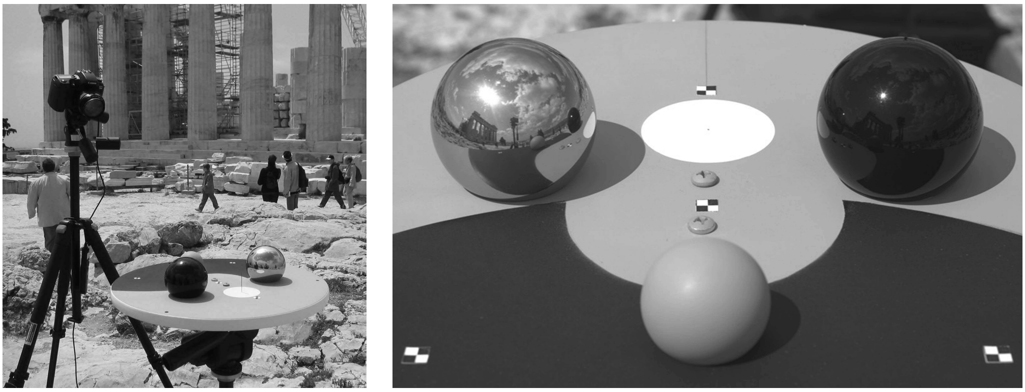
FIGURE 6.4
(a) Inferring a BRDF based on its Lambertian component ρ_d; (b) Rendered spheres with measured and inferred BRDFs. Back row: the measured black, brown, and tan surfaces. Middle row: intermediate BRDFs along the subspace S. Front row: inferred BRDFs for materials with Lambertian colors not on S.

6.3.3 Natural Illumination Capture

Each time a photograph of the site was taken, we used a device to record the corresponding incident illumination within the environment. The lighting capture device was a digital camera aimed at three spheres: one mirrored, one shiny black, and one diffuse gray. We placed the device in a nearby accessible location far enough from the principal structure to obtain an unshadowed view of the sky, and close enough to ensure that the captured lighting would be sufficiently similar to that incident upon the structure. Measuring the incident illumination directly and quickly enabled us to make use of photographs taken under a wide range of weather including sunny, cloudy, and partially cloudy conditions, and also in changing conditions.

Apparatus Design

The lighting capture device is designed to measure the color and intensity of each direction in the upper hemisphere. A challenge in capturing such data for a natural illumination environment is that the sun's intensity can exceed that of the sky by over five orders of magnitude, which is significantly beyond the range of most digital image sensors. This dynamic range surpassing 17 stops also exceeds that which can conveniently be captured using high dynamic range capture techniques. Our solution was to take a limited dynamic range photograph and use the mirrored sphere to image the sky and clouds, the shiny black sphere to indicate the position of the sun (if visible), and the diffuse grey sphere to indirectly measure the intensity of the sun. We placed all three spheres on a board so that they could be photographed simultaneously (Figure 6.5). We painted the majority of the board gray to allow a correct exposure of the device to be derived from the camera's auto-exposure function, but surrounded the diffuse sphere by black paint to minimize the indirect light it received. We also included a sundial near the top of the board to validate the lighting directions estimated from the



(a) (b)

FIGURE 6.5
(a) The incident illumination measurement device at its chosen location on the site; (b) An incident illumination dataset.

black sphere. Finally, we placed four fiducial markers on the board to estimate the camera's relative position to the device.

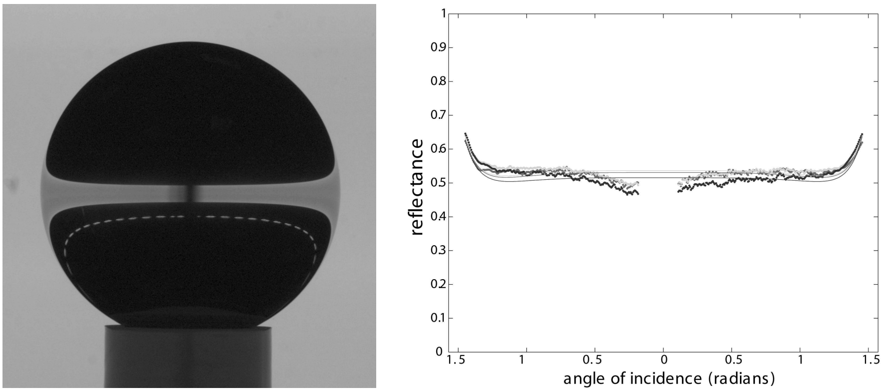
We used a Canon D30 camera with a resolution of 2,174 × 1,446 pixels to capture images of the device. Since the site photography took place up to 300m from the incident illumination measurement station, we used a radio transmitter to trigger the device at the appropriate times. Though the technique we describe can work with a single image of the device, we set the camera's internal auto-exposure bracketing function to take three exposures for each shutter release at -2, +0, and +2 stops. This allowed somewhat higher dynamic range to better image brighter clouds near the sun, and to guard against any problems with the camera's automatic light metering.

Sphere Reflectance Calibration

To achieve accurate results, we calibrated the reflectance properties of the spheres. The diffuse sphere was painted with flat gray primer paint, which we measured as having a reflectivity of (0.30, 0.31, 0.32) in the red, green, and blue color channels. We further verified it to be nearly spectrally flat using a spectroradiometer. We also exposed the paint to several days of sunlight to verify its color stability. In the above calculations, we divide all pixel values by the sphere's reflectance, producing values that would result from a perfectly reflective white sphere.

We also measured the reflectivity of the mirrored sphere, which was made of polished steel. We measured this reflectance by using a robotic arm to rotate a rectangular light source in a circle around the sphere and taking a long-exposure photograph of the resulting reflection (Figure 6.6(a)). We found that the sphere was 52% reflective at normal incidence, becoming more reflective toward grazing angles due to Fresnel reflection (Figure 6.6(b)). From the measured reflectance data we used a nonlinear optimization to fit a Fresnel curve to the data, arriving at a complex index of refraction of $(2.40 + 2.98i, 2.40 + 3.02i, 2.40 + 3.02i)$ for the red, green, and blue channels of the sphere.

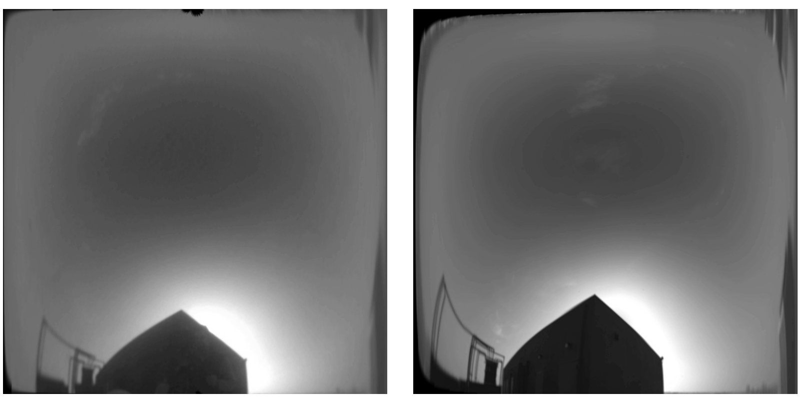
Light from a clear sky can be significantly polarized, particularly in directions perpendicular to the direction of the sun. In our work we assume that the surfaces in our scene are not highly specular, which makes it reasonable for us to disregard the polarization of the incident illumination in our reflectometry process. However, since Fresnel reflection is affected by the polarization of the incoming light, the clear sky may reflect either more or less brightly toward the grazing angles of the mirrored sphere than it should if it were photographed directly. To quantify this potential error, we photographed several clear skies reflected in the mirrored sphere and at the same time took hemispherical panoramas with a 24mm lens. Comparing the two, we found an RMS error of 5% in sky intensity between the sky photographed directly and the sky photographed as reflected in the



(a) (b)

FIGURE 6.6
(a) Mirrored sphere photographed under an even ring of light, showing an increase in brightness at extreme grazing angles (the dark gap in the center is due to light source occluding the camera). (b) Fitted Fresnel reflectance curves.

mirrored sphere (Figure 6.7). In most situations, however, unpolarized light from the sun, clouds, and neighboring surfaces dominates the incident illumination on surfaces, which minimizes the effect of this error. In Section 6.6, we suggest techniques for eliminating this error through improved optics.



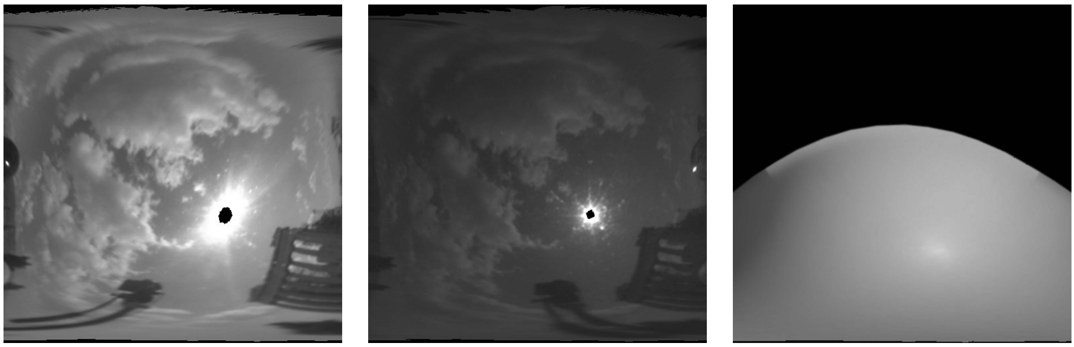
(a) (b)

FIGURE 6.7
(a) Sky photographed as reflected in a mirrored sphere; (b) Stitched sky panorama from 16 to 24mm photographs, showing slightly different reflected illumination due to sky polarization.

Image Processing and Deriving Sun Intensity

To process these images, we assemble each set of three bracketed images into a single higher dynamic range image, and derive the relative camera position from the fiducial markers. The fiducial markers are indicated manually in the first image of each day and then tracked automatically through the rest of the day, compensating for small motions due to wind. Then, the reflections in both the mirrored and shiny black spheres are transformed to 512×512 images of the upper hemisphere. This is done by forward-tracing rays from the camera to the spheres (whose positions are known) and reflecting the rays into the sky, noting for each sky point the corresponding location on the sphere. The image of the diffuse sphere is also mapped to the sky's upper hemisphere, but based on

the sphere's normals rather the reflection vectors. In the process, we also adjust for the reflectance properties of the spheres as described in Section 6.3.3, creating the images that would have been produced by spheres with unit albedo. Examples of these unwarped images are shown in Figure 6.8.



(a) (b) (c)

FIGURE 6.8
Sphere images unwarped to the upper hemisphere for the (a) Mirrored sphere; (b) Shiny black sphere; (c) Diffuse sphere D. Saturated pixels are shown in black.

If the sun is below the horizon or occluded by clouds, no pixels in the mirrored sphere image will be saturated and it can be used directly as the image of the incident illumination. We can validate the accuracy of this incident illumination map by rendering a synthetic diffuse image D' with this lighting and checking that it is consistent with the appearance of the actual diffuse sphere image D. As described in [35], this lighting operation can be performed using a diffuse convolution filter on the incident lighting environment. For our data, the root mean square illumination error for our diffuse sphere images agreed to within 2% percent for a variety of environments.

When the sun is visible, it usually saturates a small region of pixels in the mirrored sphere image. Since the sun's bright intensity is not properly recorded in this region, performing a diffuse convolution of the mirrored sphere image will produce a darker image than actual appearance of the diffuse sphere (Compare D' to D in Figure 6.9). In this case, we reconstruct the illumination from the sun as follows. We first measure the direction of the sun as the center of the brightest spot reflected in the shiny black sphere (with its darker reflection, the black sphere exhibits the most sharply defined image of the sun). We then render an image of a diffuse sphere $D^\star$ lit from this direction of illumination, using a unit-radiance infinite light source 0.53 degrees in diameter to match the subtended angle of the real sun. Such a rendering can be seen in the center of Figure 6.9.

We can then write that the appearance of the real diffuse sphere D should equal the sphere lit by the light captured in the mirrored sphere D' plus an unknown factor α times the sphere illuminated by the unit sun $D^\star$, i.e.,

$$D' + \alpha D^\star = D \tag{6.2}$$

Since there are many pixels in the sphere images, this system is overdetermined, and we compute the red, green, and blue components of α using least squares as $\alpha D^\star \approx D - D'$. Since $D^\star$ was rendered using a unit radiance sun, α indicates the radiance of the sun disk for each channel. For efficiency, we keep the solar illumination modeled as the directional disk light source, rather than updating the mirrored sphere image M to include this illumination. As a result, when we create renderings with the measured illumination, the solar component is more efficiently simulated as a direct light source.

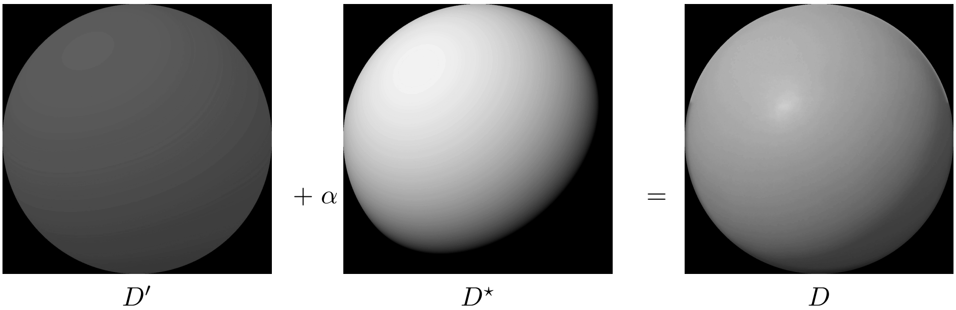


FIGURE 6.9
Solving for sun intensity α based on the appearance of the diffuse sphere D and the convolved mirrored sphere D'.

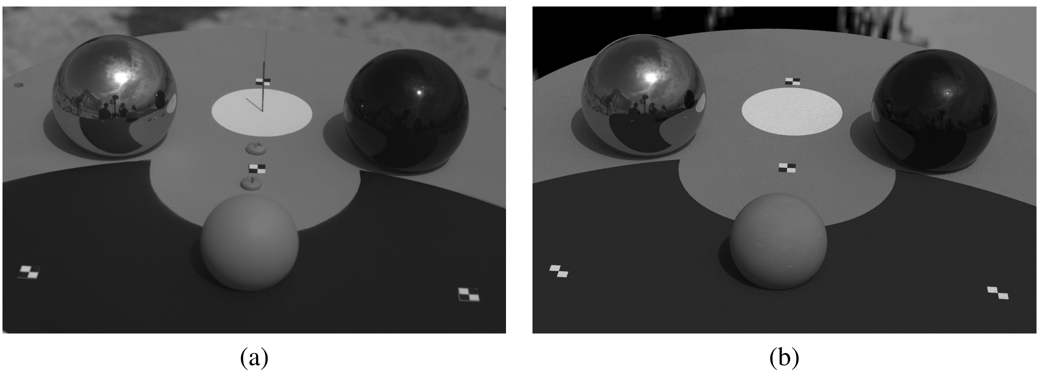


FIGURE 6.10
(a) Real photograph of the lighting capture device; (b) Synthetic rendering of a 3D model of the lighting capture device to validate the lighting measurements.

We note that this process does not reconstruct correct values for the remaining saturated pixels near the sun; the missing illumination from these regions is effectively added to the sun's intensity. Also, if the sun is partially obscured by a cloud, the center of the saturated region might not correspond precisely to the center of the sun. However, for our data the saturated region has been sufficiently small that this error has not been significant. Figure 6.10 shows a lighting capture dataset and a comparison rendering of a model of the capture apparatus, showing consistent captured illumination.

6.3.4 3D Scanning

To obtain 3D geometry for the scene, we used a time-of-flight panoramic range scanner manufactured by Quantapoint, Inc., which uses a 950nm infrared laser measurement component [36]. In high-resolution mode, the scanner acquires scans of 18,000 by 3,000 3D points in 8 minutes, with a maximum scanning range of 40m and a field of view of 360 degrees horizontal by 74.5 degrees vertical. Some scans from within the structure were scanned in low-resolution, acquiring one-quarter the number of points. The data returned is an array of (x,y,z) points as well as a 16-bit monochrome image of the infrared intensity returned to the sensor for each measurement. Depending on the strength of the return, the depth accuracy varied between 0.5cm and 3cm. Over five days, 120 scans were acquired in and around the site, of which 53 were used to produce the model in this chapter (Figure 6.11).

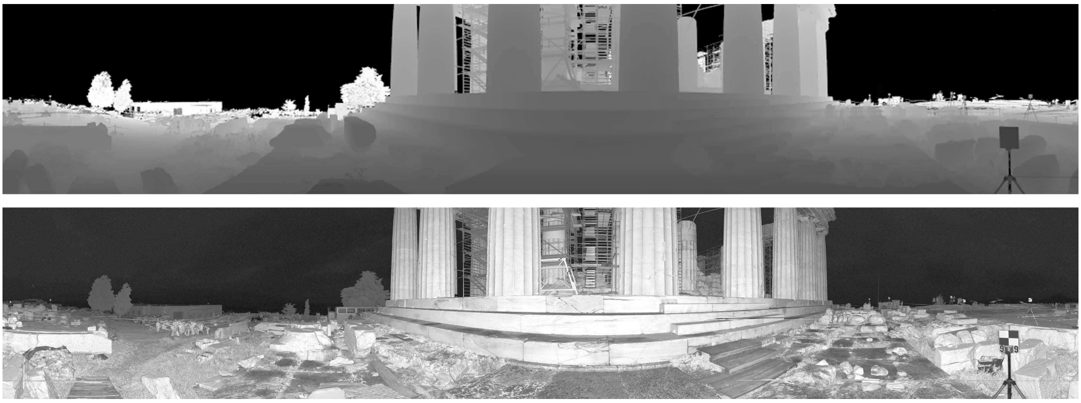


FIGURE 6.11
Range measurements, shaded according to depth (top), and infrared intensity return (bottom) for one of 53 panoramic laser scans used to create the model. A fiducial marker appears at right.

Scan Processing

Our scan processing followed the traditional process of alignment, merging, and decimation. Scans from outside the structure were initially aligned during the scanning process through the use of checkerboard fiducial markers placed within the scene. After the site survey, the scans were further aligned using an iterative closest point (ICP) algorithm [9, 10] implemented in the CNR-Pisa 3D scanning toolkit [37] (see Chapter 3). To speed the alignment process, three or more subsections of each scan corresponding to particular scene areas were cropped out and used to determine the alignment for the entire scan.

For merging, the principal structure of the site was partitioned into an $8 \times 17 \times 5$ lattice of voxels 4.3 meters on a side. For convenience, the grid was chosen to align with the principal architectural features of the site. The scan data within each voxel was merged by a volumetric merging algorithm [12] also from the CNR-Pisa toolkit using a volumetric resolution of 1.2cm. Finally, the geometry of a $200m \times 200m$ area of surrounding terrain was merged as a single mesh with a resolution of 40cm.

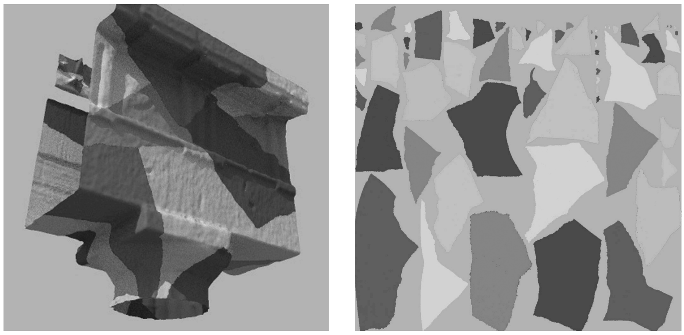
Several of the merged voxels contained holes due to occlusions or poor laser return from dark surfaces. Since such geometric inconsistencies would affect the reflectometry process, they were filled using semi-automatic tools with Geometry Systems, Inc. GSI Studio software (Figure 6.12).

Our reflectometry technique determines surface reflectance properties which are stored in texture maps. We used a texture atlas generator [38] based on techniques in [39] to generate a 512×512 texture map for each voxel. Then, a low-resolution version of each voxel was created using the Qslim software [40] based on techniques in [41]. This algorithm was chosen since it preserves edge polygons, allowing low-resolution and high-resolution voxels to connect without seams, and since it preserves the texture mapping space, allowing the same texture map to be used for either the high- or low-resolution geometry.

The complete high-resolution model of the main structure used 89 million polygons in 442 non-empty voxels (Figure 6.13). The lowest-resolution model contained 1.8 million polygons, and the surrounding environment used 366K polygons.

6.3.5 Photograph Acquisition and Alignment

Images were taken of the scene from a variety of viewpoints and lighting conditions using the Canon 1Ds camera. We used a semi-automatic process to align the photographs to the 3D scan data. We began by marking approximately 15 point correspondences between each photo and the infrared



(a) (b)

FIGURE 6.12 (SEE COLOR INSERT)
(a) Geometry for a voxel colored according to texture atlas regions; (b) The corresponding texture atlas.

intensity return image of one or more 3D scans, forming a set of 2D to 3D correspondences. From this we estimated the camera pose using Intel's OpenCV library, achieving a mean alignment error of between 1 and 3 pixels at $4,080 \times 2,716$ pixel resolution. For photographs with higher alignment error, we use an automatic technique to refine the alignment based on comparing the structure's silhouette in the photograph to the model's silhouette seen through the recovered camera as in [42], using a combination of gradient-descent and simulated annealing.

6.4 Reflectometry

In this section we describe the central reflectometry algorithm used in this work. The basic goal is to determine surface reflectance properties for the scene such that renderings of the scene under captured illumination match photographs of the scene taken under that illumination. We adopt an inverse rendering framework as in [21, 29] in which we iteratively update our reflectance parameters until our renderings best match the appearance of the photographs. We begin by describing the basic algorithm and continue by describing how we have adapted it for use with a large dataset.

6.4.1 General Algorithm

The basic algorithm we use proceeds as follows:

1. Assume initial reflectance properties for all surfaces
2. For each photograph:
   (a) Render the surfaces of the scene using the photograph's viewpoint and lighting
   (b) Determine a reflectance update map by comparing radiance values in the photograph to radiance values in the rendering
   (c) Compute weights for the reflectance update map
3. Update the reflectance estimates using the weightings from all photographs
4. Return to step 2 until convergence

FIGURE 6.13
Complete model assembled from the 3D scanning data, including low-resolution geometry for the surrounding terrain. High- and medium-resolution voxels used for the multiresolution reflectance recovery are indicated in white and blue.

For a pixel's Lambertian component, the most natural update for a pixel's Lambertian color is to multiply it by the ratio of its color in the photograph to its color in the corresponding rendering. This way, the surface will be adjusted to reflect the correct proportion of the light. However, the indirect illumination on the surface may change in the next iteration since other surfaces in the scene may also have new reflectance properties, requiring further iterations.

Since each photograph will suggest somewhat different reflectance updates, we weight the influence a photograph has on a surface's reflectance by a confidence measure. For one weight, we use the cosine of the angle at which the photograph views the surface. Thus, photographs which view surfaces more directly will have a greater influence on the estimated reflectance properties. As in traditional image-based rendering (e.g., [43]), we also downweight a photograph's influence near occlusion boundaries. Finally, we also downweight an image's influence near large irradiance gradients in the photographs since these typically indicate shadow boundaries, where small misalignments in lighting could significantly affect the reflectometry.

In this work, we use the inferred Lafortune BRDF models described in Sec. 6.3.2 to create the renderings, which we have found to also converge accurately using updates computed in this manner. This convergence occurs for our data since the BRDF colors of the Lambertian and retroreflective lobes both follow the Lambertian color, and since for all surfaces most of the photographs do not observe a specular reflection. If the surfaces were significantly more specular, performing the updates according to the Lambertian component alone would not necessarily converge to accurate reflectance estimates. We discuss potential techniques to address this problem in the future work section.

6.4.2 Multiresolution Reflectance Solving

The high-resolution model for our scene is too large to fit in memory, so we use a multiresolution approach to computing the reflectance properties. Since our scene is partitioned into voxels, we

can compute reflectance property updates one voxel at a time. However, we must still model the effect of shadowing and indirect illumination for the rest of the scene. Fortunately, lower-resolution geometry can work well for this purpose. In our work, we use full-resolution geometry (approx. 800K triangles) for the voxel being computed, medium-resolution geometry (approx. 160K triangles) for the immediately neighboring voxels, and low-resolution geometry (approx. 40K triangles) for the remaining voxels in the scene. The surrounding terrain is kept at a low resolution of 370K triangles. The multiresolution approach results in over a 90% data reduction in scene complexity during the reflectometry of any given voxel.

Our global illumination rendering system was originally designed to produce 2D images of a scene for a given camera viewpoint using path tracing [44]. We modified the system to include a new function for computing surface radiance for any point in the scene radiating toward any viewing position. This allows the process of computing reflectance properties for a voxel to be done by iterating over the texture map space for that voxel. For efficiency, for each pixel in the voxel's texture space, we cache the position and surface normal of the model corresponding to that texture coordinate, storing these results in two additional floating-point texture maps.

1. Assume initial reflectance properties for all surfaces.
2. For each voxel V:
   - Load V at high resolution, V's neighbors at medium resolution, and the rest of the model at low resolution.
   - For each pixel p in V's texture space:
     - For each photograph I:
       * Determine if p's surface is visible to I's camera. If not, break. If so, determine the weight for this image based on the visibility angle, and note pixel q in I corresponding to p's projection into I.
       * Compute the radiance l of p's surface in the direction of I's camera under I's illumination.
       * Determine an updated surface reflectance by comparing the radiance in the image at q to the rendered radiance l.
     - Assign the new surface reflectance for p as the weighted average of the updated reflectances from each I.
3. Return to step 2 until convergence

Figure 6.14 shows this process of computing reflectance properties for a voxel. Figure 6.14(a) shows the 3D model with the assumed initial reflectance properties illuminated by a captured illumination environment. Figure 6.14(b) shows the voxel texture-mapped with radiance values from a photograph taken under the captured illumination in (a). Comparing the two, the algorithm determines updated surface reflectance estimates for the voxel, shown in Figure 6.14(c). The second iteration compares an illuminated rendering of the model with the first iteration's inferred BRDF properties to the photograph, producing new updated reflectance properties shown in Fig. 6.14(d). For this voxel, the second iteration produces a darker Lambertian color for the underside of the ledge, which results from the fact that the *black* BRDF sample measured in Section 6.3.2 has a higher proportion of retroreflection than the average reflectance. The second iteration is computed with a greater number of samples per ray, producing images with fewer noise artifacts. Reflectance estimates for three voxels of a column on the East facade are shown in texture atlas form in Figure 6.15. Reflectance properties for all voxels of the two facades are shown in Figures 6.16(b) and 6.19(d). For our model, the third iteration produces negligible change from the second, indicating convergence.

(a) (b) (c) (d)

FIGURE 6.14 (SEE COLOR INSERT)
Computing reflectance properties for a voxel (a) Iteration 0: 3D model illuminated by captured illumination, with assumed reflectance properties; (b) Photograph taken under the captured illumination projected onto the geometry; (c) Iteration 1: New reflectance properties computed by comparing (a) to (b). (d) Iteration 2: New reflectance properties computed by comparing a rendering of (c) to (b).

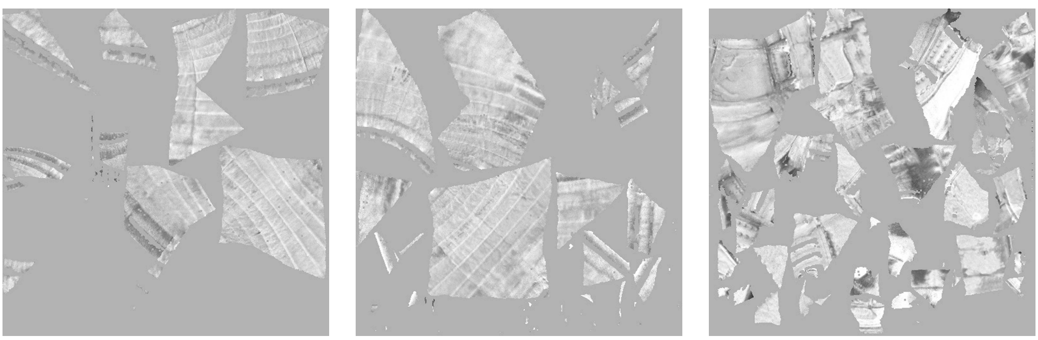
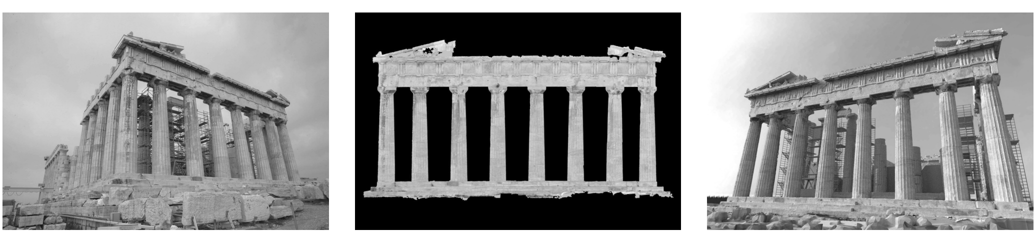


FIGURE 6.15
Estimated surface reflectance properties for an East facade column in texture atlas form.



(a) (b) (c)

FIGURE 6.16
(a) One of eight input photographs; (b) Estimated reflectance properties; (c) Synthetic rendering with novel lighting.

6.5 Results

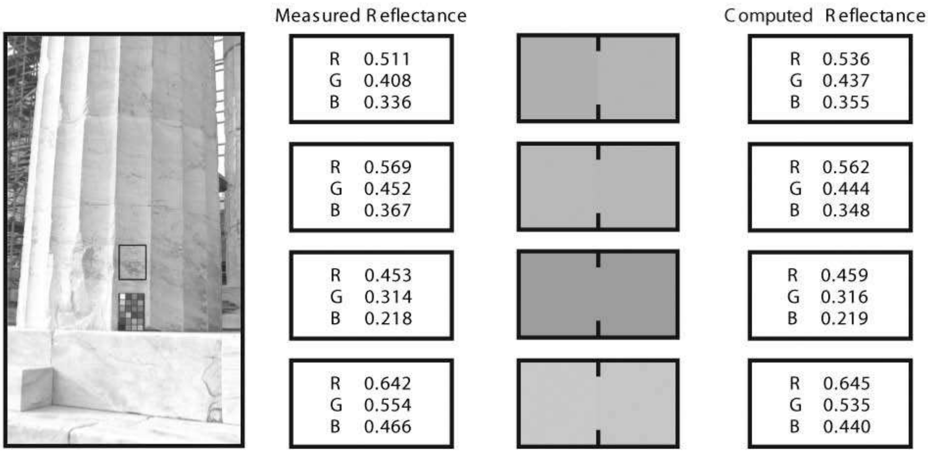


FIGURE 6.17 (SEE COLOR INSERT)
Left: Acquiring a ground truth reflectance measurement. Right: Reflectance comparisons for four locations on the East facade.

We ran our reflectometry algorithm on the 3D scan dataset, computing high-resolution reflectance properties for the two westmost and eastmost rows of voxels. As input to the algorithm, we used eight photographs of the East facade (e.g., Figure 6.16(a)) and three of the West facade, in an assortment of sunny, partly cloudy, and cloudy lighting conditions. Poorly scanned scaffolding which had been removed from the geometry was replaced with approximate polygonal models in order to better simulate the illumination transport within the structure. The reflectance properties of the ground were assigned based on a sparse sampling of ground truth measurements made with a MacBeth chart. We recovered the reflectance properties in two iterations of the reflectometry algorithm. For each iteration of the reflectometry, the illumination was simulated with two indirect bounces using the inferred Lafortune BRDFs. Computing the reflectance for each voxel required an average of ten minutes.

Figures 6.16(b) and 6.19(d) show the computed Lambertian reflectance colors for the East and West facades, respectively. Recovered texture atlas images for three voxels of the East column second from left are shown in Figure 6.15. The images show few shading effects, suggesting that the maps have removed the effect of the illumination in the photographs. The subtle shading observable toward the back sides of the columns is likely the result of incorrectly computed indirect illumination due to the remaining discrepancies in the scaffolding.

Figures 6.19(a) and (b) show a comparison between a real photograph and a synthetic global illumination rendering of the East facade under the lighting captured for the photograph, indicating a consistent appearance. The photograph represents a significant variation in the lighting from all images used in the reflectometry dataset. Figure 6.19(c) shows a rendering of the West facade model under novel illumination and viewpoint. Figure 6.19(e) shows the East facade rendered under novel artificial illumination. Figure 6.19(f) shows the East facade rendered under sunset illumination captured from a different location than the original site. Figure 6.18 shows the West facade rendered using high-resolution lighting environments captured at various times during a single day.

To provide a quantitative validation of the reflectance measurements, we directly measured the reflectance properties of several surfaces around the site using a MacBeth color checker chart. Since

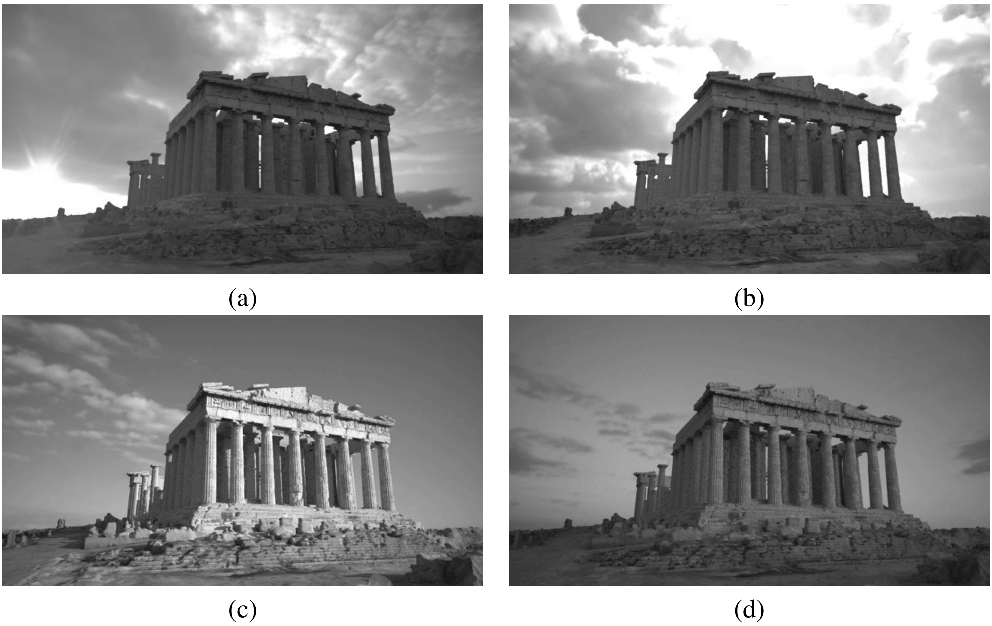


FIGURE 6.18 (SEE COLOR INSERT)
Rendering of a virtual model of the Parthenon with lighting from 7:04am (a), 10:35am (b), 4:11pm (c), and 5:37pm (d). Capturing high-resolution outdoor lighting environments with over 17 stops of dynamic range with time lapse photography allows for realistic lighting.

the measurements were made at normal incidence and in diffuse illumination, we compared the results to the Lambertian lobe directly, as the specular and retroreflective lobes are not pronounced under these conditions. The results tabulated in Figure 6.17 show that the computed reflectance largely agreed with the measured reflectance samples, with a mean error of $(2.0\%, 3.2\%, 4.2\%)$ for the red, green, and blue channels.

6.6 Discussion and Future Work

Our experiences with the process suggest several avenues for future work. Most importantly, it would be of interest to increase the generality of the reflectance properties which can be estimated using the technique. Our scene did not feature surfaces with sharp specularity, but most scenes featuring contemporary architecture do. To handle this larger gamut of reflectance properties, one could imagine adapting the BRDF clustering and basis formation techniques in [5] to photographs taken under natural illumination conditions. Our technique for interpolating and extrapolating our BRDF samples is relatively simplistic; using more samples and a more sophisticated analysis and interpolation as in [32] would be desirable. A challenge in adapting these techniques to natural illumination is that observations of specular behavior are less reliable in natural illumination conditions. Estimating reflectance properties with increased spectral resolution would also be desirable.

In our process the photographs of the site are used only for estimating reflectance, and are not used to help determine the geometry of the scene. Since high-speed laser scan measurements can be noisy, it would be of interest to see if photometric stereo techniques as in [2] could be used in conjunction with natural illumination to refine the surface normals of the geometry. Yu et al. [6] for

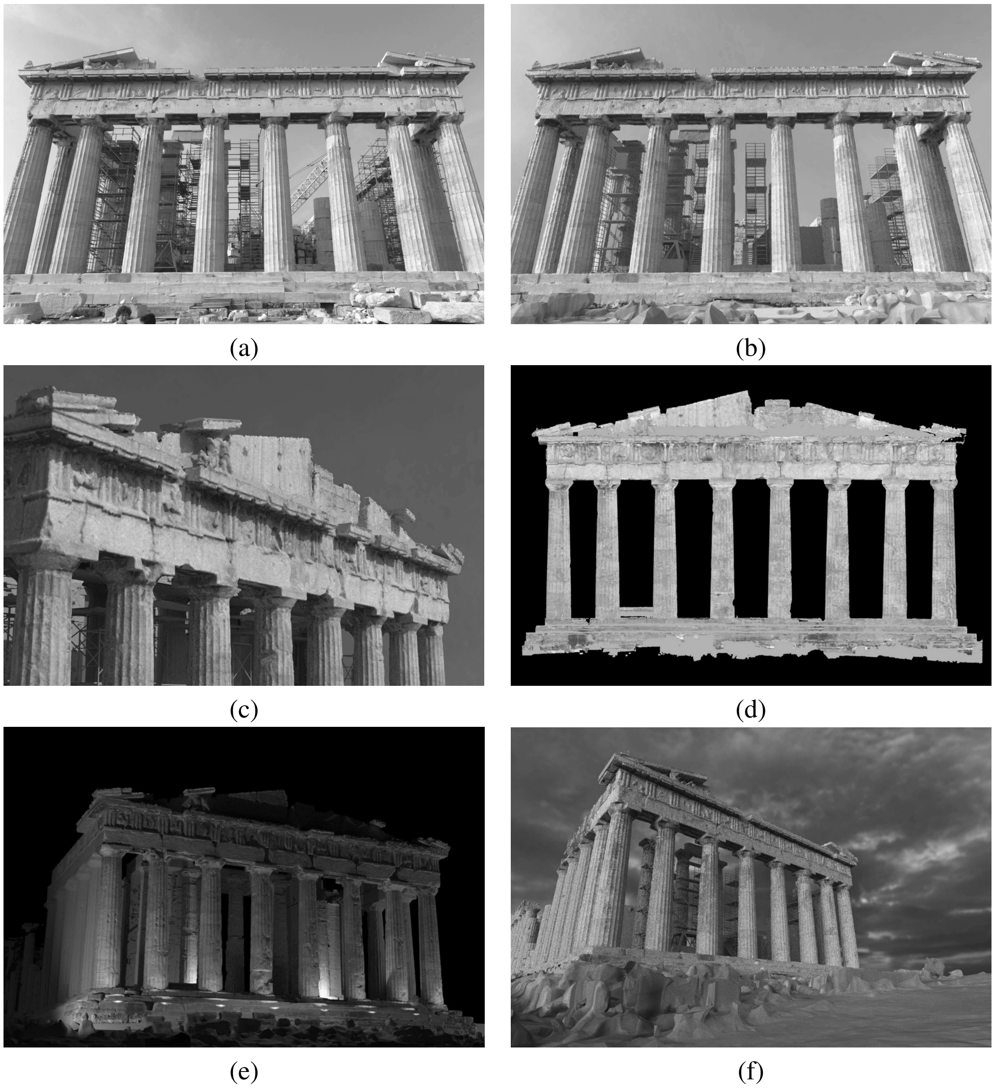


FIGURE 6.19 (SEE COLOR INSERT)
(a) A real photograph of the East facade, with recorded illumination; (b) Rendering of the model under the illumination recorded for (a) using inferred Lafortune reflectance properties; (c) A rendering of the West facade from a novel viewpoint under novel illumination. (d) Front view of computed surface reflectance for the West facade (the East is shown in 6.16(b)). A strip of unscanned geometry above the pediment ledge has been filled in and set to the average surface reflectance. (e) Synthetic rendering of the West facade under a novel artificial lighting design. (f) Synthetic rendering of the East facade under natural illumination recorded for another location. In these images, only the front two rows of outer columns are rendered using the recovered reflectance properties; all other surfaces are rendered using the average surface reflectance.

example used photometric stereo from different solar positions to estimate surface normals for a building's environment; it seems possible that such estimates could also be made given three images of general incident illumination with or without the sun.

Our experience calibrating the illumination measurement device showed that its images could be affected by sky polarization. We tested the alternative of using an upward-pointing fisheye lens to image the sky, but found significant polarization sensitivity toward the horizon as well as undesirable lens flare from the sun. More successfully, we used a 91% reflective aluminum-coated hemispherical lens and found it to have less than 5% polarization sensitivity, making it suitable for lighting capture. For future work, it might be of interest to investigate whether sky polarization, explicitly captured, could be leveraged in determining a scene's specular parameters [45].

Finally, it could be of interest to use this framework to investigate the more difficult problem of estimating a scene's reflectance properties under unknown natural illumination conditions. In this case, estimation of the illumination could become part of the optimization process, possibly by fitting to a principal component model of measured incident illumination conditions.

6.7 Conclusion

We have presented a process for estimating spatially-varying surface reflectance properties of an outdoor scene based on scanned 3D geometry, BRDF measurements of representative surface samples, and a set of photographs of the scene under measured natural illumination conditions. Applying the process to a real-world archaeological site, we found it able to recover reflectance properties close to ground truth measurements, and able to produce renderings of the scene under novel illumination consistent with real photographs. The encouraging results suggest further work be carried out to capture more general reflectance properties of real-world scenes using natural illumination.

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Archives of the Impossible, Rice University
Oral history interview of Dr. Jacques Vallee, online via Zoom
Interviewers: Timothy Grieve-Carlson and Learned Foote
Interview date: February 11, 2021
Duration: 02:03:18

Tim Grieve-Carlson: Hello, Jacques.

Jacques Vallée: Good afternoon.

Tim Grieve-Carlson: How are you today?

Jacques Vallée: I'm good. And how is Texas?

Tim Grieve-Carlson: Oh, it's all right. Yeah. Nice and warm down here even in the wintertime. And how about you? Are you in, uh, in San Francisco?

Jacques Vallée: Yes, I am. Yes.

Tim Grieve-Carlson: Very nice.

Jacques Vallée: Uh, um, can you see me all right?

Tim Grieve-Carlson: Yeah.

Jacques Vallée: Too much light or –

Tim Grieve-Carlson: No, it's perfect.

Jacques Vallée: Okay.

Tim Grieve-Carlson: How about you? Am I, am I audible?

Jacques Vallée: Yeah, you are perfect.

Tim Grieve-Carlson: Great. I'll go ahead and pause the recording here. All right. Hello, everyone. My name is Tim Grieve-Carlson. I'm a Ph.D. researcher at Rice University here to conduct the oral history interview with Dr. Jacques Vallée, and I'll let everyone introduce themselves.

Learned Foote: Uh, I'll jump in quickly before, um, uh, uh, Jacques Vallée, uh, we get into the discussion with him. I am also a, uh, grad student at Rice, uh, with, with Tim and have had the immense pleasure over the past few years of helping to, uh, assist with this, uh, this collection that's being put together; and just the, the impact of seeing all the boxes and all the research over so many decades over, all over the entire world, these documents being collected is

incredible; uh, and it's, it's just inspiring to think about, um, uh, what use will be made of these in the, the decades, uh, to come. Uh, so, uh, just want to say a huge thank you to making this, uh, this possible, Jacques.

Jacques Vallée: Well, uh, I should thank you and Rice, also, because, you know, usually, uh, a researcher leaves a bunch of boxes and papers and so on; and then, uh, uh, you know, his, his wife or his children have the task of either throwing it all away with great guilt or trying to do something with it; and if they give it to a university, it usually goes into a basement, and, you know, it's available in theory, but it's, it gets quickly forgotten; and I, I've seen that, of course, again and again with colleagues of mine and, and things I, I would've liked to look at that were not available. So, um, it's a, actually a great pleasure for me to, um, you know, to, to know that this will be preserved and that it's available to, to people now. Um, as you know, in the paperwork, uh, I, I put a 10--year, you know, period during which it's not available generally publicly; and that's mostly, it's not to protect me because I, you know, I don't think there is anything very objectionable. I mean, everything can be critiqued, but I don't think there is anything objectionable in, in any of this; but I do have to protect the witnesses and the people who've corresponded with me and so on. Uh, and, uh, I think a 10--year, you know, lag is, uh, now, this, it's not accurate to say that it's not going to be available. I think it's, but the decision will be certainly, you know, Jeff has access to it. His, you know, body of, of, uh, students, the student body and working under him, like you guys, you know, certainly has free access to it and to me since I'm not dead yet. You know, so I can, if, if there is some ambiguity in the data, uh, I can still explain some of it; uh, but, um, it could be, you know, if there is bona fide researcher outside, and I've designated, uh, you know, uh, Dr. Nolan and, uh, Dr. Pasulka, you know, obviously, have access to it now, uh, and others, it's on your, you know, your discretion and Jeff's discretion to give access.

Learned Foote: I was wondering and it, it's clear when thinking about a donation of this kind, there are so many dynamics to consider in terms of, uh, the witnesses, as you said, when does it become available to a, uh, a researching, um, body; and I'm curious, as to, uh, in terms of making that decision to entrust your archive to Rice, could you tell us more about what's, uh, enabled that decision to, to make that donation. Uh, possibly your relationship with Jeff may have played a role here. I'm curious about what motivated you to, uh, to choose Rice as the repository.

Jacques Vallée: Well, um, over the years, of course, I, I've seen, um, collections being donated to universities with no further, you know, even, even indexing and, uh, you know, boxes and boxes of books and documents going to, as I said, into a basement somewhere; and, obviously, I, I've thought long and hard about what would happen to the stuff that I had collected; and, uh, you know, I was in, inspired by, I think, by a sense of pity for the poor librarian who would get all this, you know, without any organization or, or direction. I mean, who are these people that, you know, uh, Vallée thought were so important, you know, that he would write to them every week? So, um, to the extent that I, and I'm the best person to sort of sort through that. Believe me, I've thrown out just as much material as what you have, which was either repetitive or I knew was already there, you know, on, scanned on the Internet or whatever; and I concentrated on the things that would not be so easily found and, and then, uh, you know, I wanted to organize it. Now, Rice, obviously, um, you know, Jeff played a big part

of that because we've worked on material before; and, uh, Rice, um, um, of course, is, you know, has a superb, and I visited the library and, and the stacks and so on, and, uh, actually, they are the ones who told me what kind of folder to buy, you know, for, for some of the files. So I learned how to do it so it could be easily transferred. Um, so that was very professional. The fact that, uh, I know that Jeff intends to write a series of, of books now on the development of the phenomenon and the problem in, in general, and he told me that this could feed into, into that; and so I wanted to make it available, you know, to him. The, the other, so this is the overt thing. The covert thing is, uh, you know, uh, the, uh, the department where you are, um, is studying spirituality in a large sense and under the name of religion, but, but beyond religion, it's spirituality and, and, you know, philosophy of, uh, uh, both perception and reflection on the world. Um, I would be afraid of, I had been, um, contacted by Northwestern and by Stanford to give the collections to them; and, you know, there are horror stories in this field where things have been, that were important at some time, had been donated to a university, and then the physics department says, "Why are we wasting shelf space for this garbage? You know, let's throw it away"; and, uh, I could cite some universities where things that were donated by the founders of the university, it ended up being thrown away because they had to do with stupid subjects like parapsychology. So, um, and there is one not far from, from here south of where I am. Uh, and I think that's a scandal, and the fact that you are not subject to sort of the, the abuse of, uh, all the vagaries of, you know, ideas and doctrines and theories, uh, in this way, that you can, you can keep things over a long time and, uh, and I, I know you intend to do that, so that's reassuring to me because I've been in, in a way I'm the custodian. I mean, I'm, I'm giving it as a gift, but I'm really the custodian of thoughts and writings that have been entrusted to me by, you know, by people, by witnesses, by other, you know, people corresponding with me and so on. So I have a duty to preserve it and to make it available through people who care, and that's a relationship that I feel with, with Rice and with Jeff.

Learned Foote: Thank you. I wanted to follow up on one of those remarks. You mentioned how the Rice department is, um, especially Jeff, uh, is studying spirituality in a larger sense, religion, philosophy; um, and it's, uh, within the Woodson Research Center, uh, it wouldn't necessarily just be a reli, it's not coded as just religious studies, of course. Your, your, uh, donations are much broader, uh, significantly broader than just that lens, and you have, uh, much scientific material, as well. Um, and I'm thinking it strikes me what you said about, uh, universities, other universities might want to pick and choose, whereas we're really interested in the whole kit and kaboodle so to speak.

Jacques Vallée: Mm.

Learned Foote: Uh, we don't want to leave things out, and I see it from a historical perspective. It's important to have as complete a picture as possible, um, but I'm curious if you could speak about these, these different disciplines. If someone were to only approach it, say, through science or only through religion or only through humanities, what are the ways, does your work transcend these, um, these categories in some way? Uh, and is it important to have it all together to get that, the complete picture?

Jacques Vallée: Well, it, in a way it transcends it because we don't know, we don't understand the phenomenon. I mean, if we understood it, we could say, "Well, it's, you know,

astronomy," or "It's physics," or "It's, you know, uh, it relates to this particular theory," and so on. So there would be a label on it, and it would go into, into that label. The fact that the, the phenomenon is so varied, it can be approached, you know, from Carl Jung's point of view, uh, in psychiatry in a wide sense but, you know, extended to spirituality. It can be approached as religion. I mean, look at the Bible. I mean, and, and some of the writing here goes into, as you know, I've tried to go with different groups of people into the medieval history, into the, you know, ancient history of the phenomenon to see when did this begin. I mean, and was it different in those days than it is now. Is there something that we haven't picked up in, you know, the history of civilization? I mean, it, um, or anthropology or an, anything else. Um, I think what, you know, nobody has one key to this. So, uh, that makes it more exciting, in a way. Uh, now, from a, a purely scientific point of view, it's a disappointment because we'd like to have, you know, one methodology, one, you know, set of criteria we could apply to it; but we can't do that. We are, it's too early. So the diversity of the, of the collection, uh, I think is, is an asset in a way.

Tim Grieve-Carlson: Jacques, earl, earlier you mentioned, uh, a few of those people that you, uh, found yourself corresponding with on a weekly basis, and I wonder if you could tell us a little bit about the French ufologist, Aimé Michel, who was an important influence on your early interest in UFOs and I think your decision to pursue serious scientific work in this area. Um, this correspondence is part of the collection. I wonder if you could just tell us a little bit about Michel and your relationship with him.

Jacques Vallée: Um, Aimé Michel was, um, maybe typical of, um, no, I, I, I couldn't say he was typical of anything; but he, he was part of, um, a, a, a, a French way of thinking that, uh, was both, um, you know, rested on, on rationalism and, and science, but he was also a scholar, um, of antiquity, uh, Greek and Latin; and, uh, he was, uh, very interested in spirituality, and he was also, I mean, professionally, when I met him, was working in a unit of the French radio and television, mostly radio in those days, started right after the war, that was very, very experimental and very, it doesn't exist anymore except in little, little pockets; but there, there was a cadre of, uh, young people who emerged from World War II, uh, enthusiastic about electronics, about broadcasting, about reaching the public with big ideas and were scholars, uh, which, I mean, obviously, you know, the, the media has become businesses, and it's driven by business now; and there is no, none of that opportunity for real-time experimentation with a public medium; and because at, at that time right after the war, you know, uh, the French radio was a state organization, um, just like, you know, a state university, they could do research and could do whatever they wanted. So it was very, um, they made, did a, a number of, um, uh, interviews, uh, with, uh, leading thinkers, uh, and then he contributed his own research; and, and when the, uh, UFO problem and, and other things in parapsychology, uh, came up, he had, uh, both the talent and, and access to people because he came from the state organization, uh, but he also had sort of a license to talk about anything. So he looked at, at parapsychology, and he started looking at UFOs. He started looking at UFOs as a fad; and, you know, Hynek will tell you the same thing. He says that he, he started thinking it was, like, you know, swallowing gold fish, you know, a fad that, something that people did that didn't amount to anything. It was just a strange sociological thing; and then, uh, actually, Jean Couteau, who was a friend of, of Aimé Michel, is the one who told him, you know, "You're wrong. These people have seen something, and they've seen something you should research because we don't, we don't understand it. It's

new. It's, um," so, and he, you know, listened to that advice, and he, uh, started corresponding with people; and there was a major wave in France in 1954 that I remembered because, eh, uh, I remembered it as a teenager. I collected, you know, uh, papers from that era, uh, cutting it up out of newspaper and fixing it on, you know, copy books and so on, uh, to try to make some sense out of it because it was so, so amazing; and, um, uh, Aimé started digging into that because he had access to, of course, to, to the information network of, of the French radio and television which, again, was a state agency. Uh, and, uh, so when, uh, uh, I met him through, uh, Pierre Guérin, who was a, an astronomer that I consulted, um, when I was working at Paris Observatory, and he said, "You should go talk to Aimé," and that's how the, our friendship developed; and he turned over his files to me because he was delighted to see that there was somebody who could put this on a computer and start looking for patterns because he thought that there were patterns behind the data.

Tim Grieve-Carlson: So, Jacques, you mentioned that, that was wonderful. Thank you. You mentioned, uh, J. Allen Hynek for a moment there, and I have, he's another person who's represented in your archive and another person with whom you worked very closely for a long time; and, um, Hynek's also kind of undergoing this kind of popular, uh, reevaluation. There's a, a new biography, uh, and, uh, this television program. Um, you, you knew Hynek very well, and I wonder, uh, what you might tell us about Hynek in light of all this kind of recent publicity.

Jacques Vallée: I think the most important thing to understand about Hynek that people didn't understand at the time in part because he kept it from, as a, sort of, not, not as a secret, but as a, as a personal quest, was that he was very interested in spirituality. He was very interested in, uh, the metaphysical traditions; and, um, among other things, the Rosicrucian tradition. Um, he was interested in parapsychology and even in astrology. So no wonder he wasn't bragging about that at, you know, Harvard College, but, uh, he, his mind was, was very, uh, uh, very much advanced; and, uh, remember, he came from a, a Czech, uh, fa, family, uh, immigrated to the, to the U.S., and I think he brought that. He was raised, I think his mother was very influential on his thinking, and, uh, uh, you know, he, he told me that, that sort of family tra, origin from Central Europe contributed to, to, um, make him aware of, of those larger issue behind, behind science; and, and he always said, you know, you, you do science because you want to understand the world at a higher level. You don't just do science, you know, for engineering or for, uh, or just to write some nice equations. You're trying to understand something larger, and that's where we, we met because I had very much the same, you know, still do, um, you know, the same trust and the same, uh, um, uh, hope to understand more about the world through science which is one set of tools; but there are other sets of tools. Um, so, uh, when we started talking about that, we found that we were very much on the same path, uh, even though we might disagree on, you know, some aspects of, you know, some UFO reports or some, some quarrel that was going on among ufologists that, um, we rarely found the, the right approach at the higher level.

Learned Foote: Uh, I have a, a follow-up question here, and I, I'm thinking back to both of those correspondences of which there are many decades within the archive of conversations going back and forth, uh, over many years; and I'm thinking about what you mentioned with, uh, sort of the, the UFO wave that occurred in, in France. You mentioned 1954, uh, and people thinking at the time it might be a fad and might sort of come and go; and you as a, as a teenager, had a keen interest in how this was playing out, uh, direct experience, um, and so forth; and I

I'm curious. It now has been nearly 70 years since that time. Uh, it clearly has not, if it's a fad, it's a, it's a long-lasting one so to speak. Um, and I'm curious. Did you have this sense when you were getting into it as a teenager, uh, that, did it feel like something that was new? And I know that your, your research then pointed to some of the, uh, antiquity that you can look at this phenomenon through, but when you were first encountering it, did it feel like something new; or did you think it could be a fad? Are you surprised by the longevity that the, that the research has had?

Jacques Vallée: I, um, remember, I was 14, I don't know, 14 or 15. Uh, I did have a telescope and an interest in, in science, and I was good in, you know, in physics and very interested in astronomy. Um, I didn't, I didn't think it was, I never thought it was a fad. Um, to me it was a real mystery. I think that was, um, the reaction of most of the public in, in France. It wasn't, of course, the, the channel through which we heard about it was the radio. I mean, we, my parents never had a TV set, okay? So you have to put yourself in that, that time. France was still recovering, you know, slowly from the devastation of the war and so was the rest of Europe; and then this happened. Um, I thought that, um, it, it might be certainly what, what I saw, and, of course, when, when I saw it, that sort of made it pretty clear to me that, you know, this was real; but it could be real, and it could be a new development that was being tested. A, again, in those days, um, there were, you know, the first jet airplanes were being tested, or pilots were being trained to fly jets. Uh, there were, you know, helicopters. There were things that hadn't existed before. So there was, uh, a great sense of novelty and so on. So it came within that, but at the same time, um, there were all these stories about landings, about, you know, strange beings, robotlike entities, you know, running round; and there were so many of them that you, you couldn't say it, uh, that it, that people were making it up. You know? I mean, the, the people were just as surprised, and the first reaction was, was, was surprise and, uh, uh, curiosity, uh, from, from everybody; and when, um, so, I, I never, um, I, I thought this is something that feeds into, you know, my interest in science and, um, that would be, that I thought we would be able to resolve because of a power of science. You know, uh, when you are a good student, you know, you think that, uh, uh, this is going to help you understand the world; and then later you find that, yes, it helps you understand something about the world, but it, it only expands your opportunities for wonder and, you know, and questioning. So, um, I, I thought that at the time, I thought we are going to understand this; and, you know, later when I had access to computers and so on, I felt we, we're going to look for patterns, and that will tell us what it is. So that was my, my initial sort of naïve but, but well-, well-intended, you know, uh, uh, approach to it.

Learned Foote: Uh, I'm thinking now about the research that you've done over the years, and the way that they have been presented to Rice is in the form of three collections, uh, A, B and C. Uh, and I wonder if we could, if we could talk a little bit about that. In particular, Tim and I, uh, spent, uh, time over the last year looking at B and C, uh, which in large part collects, uh, um, uh, secondary material such as newsletters, newspapers and so forth, research done, uh, by secondary sources, as well as your correspondence with many figures. Um, that is the B and C, uh, but there's also this A category, uh, and I wonder if you could tell us a little bit about how your research is categorized into these, uh, and about the, the contents of, um, of A.

Jacques Vallée: Yes, well, that's, that's important. Of course, um, you know, the, in, in a topic like this everything relates to everything else so the, the question is where do you start and

how you, do you classify it so that you don't presuppose a structure that, you know, people like you coming into the research will have to, you know, throw away and, and reconstruct in a different way. So, um, in the case of C, that's very clear. Those are letters. So the medium, you know, is correspondence with people. I, I forget how many there are, but, uh, you know, it, it's pretty extensive; and it, it really covers, um, the, um, you know, the waterfront pretty well in terms of coverage certainly of, uh, uh, the U.S., France, England and, uh, you know, the, some major, major other countries like Spain and so on. So that is sort of a self-contained, uh, body. Um, you know, Section, Section B is, um, things that I collected over the, over the years. There are tapes. There are magazines that probably will exist at some point on the internet, but the internet is, is nice; but I pity people who do research just on the internet because, you know, feeling the, the paper, seeing the, the actual writing, seeing how it's related side by side with other things tells you a lot; and, um, that's in that period that I had saved those things, even those that I knew were available online somewhere, but you know, for example, Uranas is completely forgotten in France. Uranas was before everything else. It started in the, in the '50s, uh, you know, before the, the CNES became interested, before scientists became interested in the subject; and those people were good writers, and they were reporters. They were journalists. They were writers, science fiction writers, like Jimmy Guerre, very, very much a, a popular thing. That was a high-quality magazine, and, uh, I've tried to save, um, you know, at least a, not, not, I don't, there isn't a complete collection here in, in, in what you have; but, um, I've certainly saved enough that you get the, the feeling for what it was. Your other reviews like Phenomena, you know, that are not really current, um, today, but they've captured a big part of that transition from, um, you know, the early years to the, uh, the development of, of the, of ufology in the United States that has then influenced the, the rest of the world. So, so those are, um, there is overlap, but, uh, there isn't much, you know, so much overlap. A, um, of course, is, uh, the last one I did, the most recent one; and those are my files. So those are the things that sort of came, excuse me, um, uh, sort of came over the transom and landed on my desk, um, some by design and because I went there and gathered the data or randomly because somebody sent it to me or a friend or, you know, a, um, a UFO group I knew was involved and got me involved. So it's a semirandom walk through the landscape, and some of those are actual cases that are still of, of interest and are still a mystery, uh, some, some of them with photographs and recordings, things like that. Others have been explained, and so it's interesting to see how the explanation came, came about; and, uh, some are sort of in between. So, uh, there's 200 of them, and they provide a good, um, I mean, you know, if, if you looked at the body of data about UFOs, the way, uh, for example, Mr. Bigelow and, um, you know, the, the BAASS Project that I was involved with collected, uh, the, the, the total data is about 200,000 cases. Okay? Over the world, which is not much by modern computer database standards, but each one of them, of course, extends over many different fields. I mean, who are the witnesses? I know in some cases you have a hundred witnesses. Sometimes there's only two or just one, uh, uh, but we, we knew a lot about them. So every witness is a part of it. The location has its own characteristics, and then the observation itself has its own characteristics; and it, it can, of course, extend. So now the, these are very long, thin records that extend a lot and may even point to recordings, radar data, whatever; and so the, the, it's, it's a complex database, even though it's "only" 200,000 cases. Here you have 200, much of which is sort of explained. I mean, there is no more research and investigation to do, but they illustrate how society was exposed to something that somebody thought was an, an extraordinary phenomenon. So I think that's what it, what it gives you. Uh, I have kept, and I, I, I keep the data I want to work on now in, you know, in the next few years, in two areas that I, I

don't think, uh, really belong in the same collection. Um, one is, is a collection of actual samples, actual material samples; and as you know, I've, I've started to work on this with Dr. Nolan and other people at, at Stanford and in, you know, in California. Uh, and that's, that's hard science. I mean, it's material science. We want to see if, uh, the composition of these things, those are things that result either from "a crash" of something that left, that deposited some, some material, or was ejected from, uh, from an object, from a flying object and was recovered. Uh, we are trying to publish our first paper on this in a regular, uh, refereed journal, scientific journal, you know, about hard science, and if we do that, it's going to be the first paper in history refereed in a general science journal. So that's, that's an important thing. Uh, we, we want to go on, you know, to, to sort of establish a methodology for doing this and maybe open the door for others to do that with whatever they found. So that's something that is not part of the collection. The other thing that's not part of the collection is another 200 cases that I'm continuing to work on because they are unidentified, completely unidentified, and I, and I want to continue to dig into them and to research them. Um, but those would not be of as much interest to you, I think, and eventually, they may, you know, they may come to Rice; but, um, I think those are part of what I'm doing now. So I've sort of narrowed my focus on the few cases where I could, um, I could build a case in, in, you know, for a scientific approach to the hard data; and some of those I've already published things about so they are not, you know, not unknown, but I, uh, I, I need to continue to, to work on those.

Learned Foote: Marvelous. So I'm curious, uh, thinking about the A collection. You mentioned you have about 200 cases, some of which are explained, um, some of which are still a mystery and some of which are a combination of both. Um, did you, did you categorize those as sort of saying, based on your estimation of looking at these, that these are the ones you feel have been explained, these are the ones that remain, uh, to be worked on? Is that, uh, part of how you categorized in the gift?

Jacques Vallée: Uh, uh, no, and by the way, in, in B, you also have some cases like that, for example, the case of Mantel, you know the pilot who died following an object. That's still unexplained. I, I think that there is a good, good argument to say it may have been a balloon, and, um, most ufologists don't believe that. They think it was a UFO at very high altitude. Um, I, I've looked at, at both. I started from the ufologist approach, uh, thinking this was, he was chasing something and just went too high, you know, and ran out of, I mean, essentially passed out because of altitude and, and crashed. Um, in UFO books today, I, I still see it as hostile intent from a UFO destroying, you know, an American airplane. Um, the, so there are cases like that that are still in question. The reason I think it's a balloon was that there were extraordinary balloons called Skyhook that were classified, and, uh, Mantel could not have any idea of how high it was because those were very, very, very large balloons, and they were there to detect atomic explosions and that was a classified project. So he saw this. It was reported as a UFO. Of course, the Air Force explained it as the planet, Venus, which couldn't have been in that part of the sky, um, so it, you know, you have cases like that; and that, you know, those cases are in, uh, there are some cases like that in Section B. Um, the, the ones in Section A are things that I've, I've done, I've gone through it. Some of them I've, I, I came to a conclusion, and I'm done with it. So I don't need to see them again. Um, if I need to see them again, I'll fly to Houston, but, uh, the, uh, essentially, I, I'm done. Uh, some of them are very, very interesting because you see the, the arc of belief and disbelief and controversy, in some cases lawsuits and so on. Um, so

you, you see the full psychological and sociological, you know, richness of, of, of those cases. Some of them extended over several years, and people were, you know, screaming at each other about it; and, and in some cases, there is, um, actual data that deserves to be looked at. So in terms of looking at the, the mechanics of the whole phenomenon, I, I think it's, it's very rich, but those are not the ones that I want to specialize now in, just a few, a few things where, uh, I can make it, you know, a different kind of contribution.

Tim Grieve-Carlson: Well, Jacques, as much as I would like to just keep asking about your work with Dr. Nolan and, um, some of these materials, um, you know, you mentioned kind of the arc of controversy with some of these cases earlier; and, and one of the long-term research projects, um, that kind of culminated in your best-known, one of your best-known works, was Passport to Magonia, your 1969 book in which you explore the similarities between certain aspects of the UFO phenomena and, and European folklore, some particular, um, occupants, humanoids and beings kind of like the, associated with European fairy lore which appear in the works of doctors like Paracelsus. Um, I think Magonia is one of these books that you can really kind of tell a lot about a researcher by figuring out what they think about Passport to Magonia. Um, it's still kind of a, uh, a debate or maybe, uh, maybe a fault line that, that remains in the UFO community; and I wonder if you can just speak about, um, first of all why you think the book had, continues to make such an impact, even, even today, nearly, you know, um, more than 50 years later and then sort of where you stand on the positions outlined in Magonia today.

Jacques Vallée: So, um, you know, coming from France, I'd always been aware of, you know, things categorized as folklore, but folklore doesn't mean that, uh, that it's mythical; and, um, I remember early only when I was sending, you know, papers, little articles to the, the Flying Saucer Review which was this very British, you know, invention by, by some enthusiasts in, in, in London; and, um, there, there was an argument about the word myth, and Gordon Creighton who was a, was a very, uh, articulate scholar, as well as a British diplomat. He had been around the world and been in China, had been in South America, and he was back in England. So he was somebody with a great awareness of language and traditions and, and, and so on; um, and, uh, I had been attacked by an American writer saying that why was I spending all this time on myths; and Gordon Creighton said, "You know, don't react to that because there is nothing wrong with the word myth. Um, a, a, a myth is something which is more real than reality. It's not that it's not real." You know, and, and, I mean, Jesus Christ is a myth. Um, you know, miracles are, are mythical, but they are mythical because they, they relate to a type of reality which is more real than ordinary reality. They're at a different level of reality, but it doesn't mean that they are not real; and, um, that, I mean, that was an age of the, of, of the dialogue and that's, so in 1968, as, as you know, I got completely disgusted with essentially the hoax that the government was playing in, in Colorado; and with, you know, hindsight, I understand why the Air Force really, really, really wanted to get rid of UFOs because there was, there was no way to win with that. Uh, if they took it seriously, then they had all of Congress against them, and if they, if they dismissed it, then they had the rest of the population against them; and they did not have the resources or the skill to, to address the material, uh, and, uh, it was an endgame for any bright, you know, pilot or Air Force officer who was put in charge of this mess; and, uh, you know, these people want to go on flying. They don't want to be behind a desk trying to figure out, you know, what kind of star these people have seen or whether it's potentially a threat; but, you know, after 20 years of essentially no hostility on the part of the phenomenon, it doesn't

justify as a threat, and if it's not a threat, you don't need the Air Force! I mean, the Air Force isn't a fix to do so they really, really, really wanted to get rid of it, and the Condon Committee was created for that, and it was, it was very of use in, um, you know, '67, '68, that they were going to write a, a negative report, and it would be embraced by the Academy of Sciences, so and so. Uh, at that point, I got disgusted and went back to Europe. Um, it turned out what I, I went to Europe, I went back to France at a very interesting time when, uh, for all kinds of political reasons, it was near the end of the reign of de Gaulle and so on, um, there was a general strike; and, and there was nothing to do for a month, and, uh, I was in Paris where there was still, at that time, you could still buy some of these old books on traditions and so on; and now that I was outside ufology, you know, it was clear that the, the Condon Committee, the Condon Commission I should say, uh, was going to write negative report that would kill the research for 10 years, which it did, uh, I was free to think in different ways; and, uh, being back in, in good old Europe, I started looking at the, the, the data that I knew very well, uh, the data about the encounters, the close encounters; and, of course, in the meantime, I had convinced Allen Hynek that there were close encounters in the U.S. that you, even in the Air Force files, that you couldn't see because they were dismissed immediately, and the joke in the Air Force was if it's on the ground, you know, it's not the Air Force. So we'll dismiss it. Okay, and that was the, uh, an easy way to get rid of the problem, but they were there, in fact, there are more close encounter cases in the files of the Air Force than there are in the files of NICAP. So, um, that was kind of striking, and to me, that was the center certainly at that time the, the, the unexplored area. I mean, what are those things? What are those creatures? Why is there such a, a tremendous impact on society through those images of encounters in very unusual circumstances with objects we don't understand, objects of light and so on; um, and has that happened before? And when you ask, which is, you know, the obvious question in science, "Has it happened before, or is it a new phenomenon?" and when you ask that question, you unlock an entire world, you know? I mean, yeah, I mean, it didn't start with Kenneth Arnold in 1947, and there were observations before. We continue to dig up observations from, you know, the early 20th century. Um, you know, the Magonia group in, uh, all over, around the world is very active in digging that up from American newspapers that had never been looked at before because they were not online. Now, they're online. So they are searchable, and you find that here there were 10,000 local newspapers in the U.S. in 1910, and many of them had little reports of, you know, Mr. So--and-So is coming home and he saw this and so, so now we have this continuity, and it certainly extends to the 18th century and the 17th century and before; and the, when you look at patterns, and, again, remember, I'm coming to this not as a physicist, not as a psychologist, but really as a computer nerd. I mean, you know, I, I'm good, well, I've been trained to look, to use computers to look for patterns in very complex data sets, and I've contributed to that as, as you know, in computer science, in AI and so on, and, uh, that's what you do in science. You, you have a data set, and you, you, you try to look at its dimension, at its, its, uh, co, cohesion, its consistency, and that at, you know, what is connected to, to what. So that's the approach that got me to Passport to Magonia. Magonia, as you know, then, where the name comes from. I mean, it, it comes from an encounter of, uh, cloud ships, uh, in over Lyon in France, uh, where a cloud ship, whatever it is, landed and people came out and the population thought they were devils, wanted to kill them, and the, the reason this was preserved, this is not a fairytale. This is preserved in the writings of the church. This was in the 9th Century, but people wrote books and published them in Latin; and, um, you know, the book was published by the ar, archbishop of Lyon, um, explaining that these people came before him and he told the crowd that, um, they should be allowed to live.

Now, this is, you know, this is a historic event. It's recorded by the primary, you know, church, uh, who was an archbishop. His life is very well known. He has left a series of books about nature, about different phenomena and so on, about thunder. Uh, what came from God and what came from nature was a big problem for him, and he, he studied this as a philosopher. So we, we knew everything about this, and, I mean, today this would be another UFO case, and we're still asking the same question. You know, what is it that comes from nature, and what is it that is supernatural or transnatural or, or mystical? So that, that's what's, you know, and once when I found, once I found that, and I was in Paris so I could, I could go get all those books either at the, uh, Bibliothèque de Sénart or, you know, some of them I could buy, uh, in, uh, in very, very, very good, um, uh, book, specialized bookstores, you know, antique, antiquity bookstores; and, um, uh, I, I still have that book collection, and, uh, it's full of that stuff. So I really couldn't say I'm going to walk away from that because, you know, it doesn't fit the American idea of, you know, that UFOs are connected to space or to the space program and so on which is in our mythology here in the U.S., of course, that's what it is; but you have to look at the larger perspective.

Tim Grieve-Carlson: Jacques, you, uh, you mentioned – thank you for that, um, for that wonderful answer. You mentioned, uh, professionally at least your, you know, you're, as you put it, you're a computer nerd, and, uh, I want, if it's okay, I wanted to read a quick passage from your journal from Forbidden Science Volume 1, a passage that I really love, where you write, uh, this is in 1961 you were writing, quote, "The most beautiful sound I have ever heard is the pure and highly musical hum of the memory drum, the IBM 650 when the computer dies. All the power goes out. The motors are still. The console lights stop blinking and, of course, the program is lost. I become aware of the summer sun and the dusty courtyard behind me." So it – as, as you know it's rare to hear a technologist who writes, uh, so elegantly about machines and about their love of machines, and I wonder if you could just tell us a little bit about how not only, your career in technology, but also kind of your love of technology and kind of this way of thinking, as you put it, of sort of being a person who's trained to think in terms of data sets and locating patterns in data sets. If you could just talk a little bit about how this has sort of influenced your approach to the UFO phenomenon.

Jacques Vallée: Oh, um, it, you know, um, as a species we've developed, um, for example anthropologists have written lots of books about that, you know, our hands and the eye coordination with the hand and so on has developed because we use, you know, we use tools and we make tools. Um, you know, I've, uh, I worked for the, the man who invented this. I know Doug Engelbart at SRI; invented the mouse. Mouse is simply, you know, a little piece of wood in those days with, with two wheels one that goes like this and one that goes like that. If you move it around, you have a pointer, okay. Well with our bodies and the mind and body have developed in connection with a mastery of nature through the making of tools. Um, and the, the computer, um, you know, is obviously still evolving with us and is becoming more and more, more and more close to us as, you know, as a body, as an organism, as, you know, linked to, to our body but it, um, it, it provides an opportunity that one's still not using very well to access the, the world. I mean you, you see it now in, uh, you know, in, in artificial environments and video games and so on and now that are immersive, but the at the time I mean to me, uh, 650 by the time I used it was already sort of an antique, uh, machine, uh, but it, it was powerful and it enabled you of do things that you just couldn't do with pencil and paper. I mean, you know, you

might be able to compute an orbit of a satellite but it, it you might do it once. Uh, the computer could do it again and again and again and again. And you could, you could program it. You could invest your, you know, intelligence of a problem, uh, into it and then use it as a tool the way you'd use, you know, a hammer or a screwdriver. And, and, and get those results and, um, you know, I, I'm still, um, fascinated with that. I mean I'm still and to, to some extent it's, it's a pity that, um, with the computers have become so, so good and so transparent that, you know, here we can look at each other, you know, all the time in space without thinking about it, but in those days you had to think about every instruction because if you didn't it would stop and you'd lose 2 hours, but the, that, you know, it's still there underneath and to me it's, um, uh, I thought of it as a, as a magical tool, you know, the same way Paracelsus would think of, uh, a, you know, a crystal or a mirror or, you know, a or a, um, you know, a device of some sort, uh, both in medicine or in other areas or in, in a magical sense so it's, it is very much, you know, a magical tool. I've never stopped, you know, to think about it that way. Magical in a good way.

Learned Foote: I wonder if I could follow up on that with a question, uh, relating to, uh, spirituality was one of the terms you used at the, at the beginning. Uh, and I'm thinking about how you mentioned in your correspondence and friendship with, uh, with Dr. Hynek, uh, there's a shared interest Dr. Hynek had an interest in the Rosicrucians, for example, um, and you mentioned your inspirations writing, um, Passport to Magonia and being able to go around to all these book stores and read this, this literature, uh, so there's, there's a, an abiding interest in, in that dimension. At the same time when you wrote, um, Messengers of Deception, in the 1970s, uh, it's very aware of the California scene, the ways in which, uh, religious groups were developing and you pointed very, very early on before other scholars had to the group that would become Heaven's Gate, uh, when they were, when they were still just a tiny group going around meeting with, um, with a very small number of people, um, before they eventually, uh, decades later, named them, themselves Heaven's Gate. So you saw the, the foundations, uh, for what that would become and you, you raised warnings about the potential for that sort of, um, conspiratorial or, uh, that, those, that aspect of, of the UFO movement. So I'm curious when you think about spirituality how do you distinguish between, um, something more along the lines of what, uh, Hynek was doing or you were interested in doing in Magonia where you can think critically alongside engaging that material as opposed to some of the more, um, stultifying, uh, closed minded, uh, what I think of at least as closed minded religions groups like Heaven's Gate, for example, how do you with this common interest in spirituality how do you distinguish between what is critical and what falls into, um, you know, you could call it a cult, for example?

Jacques Vallée: Oh, you know, I don't need to tell you that there is a, a thin line between a cult and a religion. Um, and, um, I'm not sure that there is a good definition of where the frontier is. I mean how does it, um, how does one turn into the other? Um, you know Jim Jones is also something I've studied; uh, as you know, uh, we, my wife and I bought the property in Northern California in Redwood Valley. Um, and that's where Jim Jones had moved his church, you know, and we passed it every time we, we went to my little observatory there and to our property in the Redwoods. And he did it for the same reason we did, which is, you know, which to me is sort of, you know, uh, I see a parallel in thinking with Jim Jones, which is something that, you know, scares me. But, uh, the idea was, you know, the world is becoming extraordinarily dangerous, um, for all kinds of reasons, uh, mostly strategic reasons because we're, we could have a nuclear exchange so I mean in the '70s it was, you know, in the late '60s and '70s it was

very much a possibility, and also there might be periods where you might not be able to survive in an urban setting so the, at the same time, of course, which made the difference between me and Jim Jones, I felt we are going to have the means of communicating at a distance and working at a distance, um, and, uh, you know, which is evident now because of the virus, okay. So it did happen, okay? We can't really go to the office anymore. Uh, I mean once in a while but, uh, the we are in a situation where the people – I don't know how it is around Houston, but people in San Francisco are selling their expensive condos, you know, to, to buy a house on the coast, you know, where they are 50 miles away from their office that, uh, Facebook or whatever and, uh, Facebook says, "Yeah you, you know, we don't need you to use, to use the office, you know. Stay where you are. Work at a distance." So we, in some, in some way we were ahead of that wave but we thought that there were a number of scenarios that would make it difficult or impossible to work from an urban area. And at the same time you could be in nature. You could raise your kids in a clean environment, uh, uh, you know, away from exhaust gases and everything else and you could enjoy nature so, um, we actually got together with a group of people including some, some geologists who were working with, with computers, and we actually thought of starting an organization that would buy a big piece of land and would assign it to the different members so they could build something and we would have sort of a community that way. This was in the 70s. Now lots of people were thinking of that, of course. There were hippie communes, uh, were doing it for other reasons, and Jim Jones had the same idea of going away from the politics of, uh, of San Francisco. Um, the, um, so the, the idea also was that spirituality was still alive outside of those urban areas and that you could, uh, you could be not just closer to nature but you could be closer to friends who had the same ideas and you could, you could thrive in that kind of environment. At the same time it was extraordinarily dangerous, and I, I looked at a number of cults, you know, all the way from the diabolical, you know, all to the way to the extreme, uh, um, you know, um, super-Catholic or super-religious, uh, groups, um, with their own traditions. Now think of the group in Waco, you know, that was, uh, horribly, you know, killed. I mean by, by the power of the state, okay? Uh, but they were also actually looking for that. I mean, in, in a way similar to Jim Jones so when, when the, the Jim Jones church starting moving in that direction, yes, I, I called attention to it and nobody thought that it would amount to anything; that they had no real power; that they were dismissed. But as we see now, you know, in, uh, uh, QAnon and others you, you cannot dismiss that kind of thing. I mean you really have to engage it on an intellectual level even if you're repelled by some of the, you know, some of the things you see on TV so it, it deserves to be studied carefully and, of course, in the history of religion you have plenty of those things. So I've gone through that in, in various ways. I think what we're living through now is going to be a redefinition of what it means to work together, of what it means to communicate, and what it means to be a thinker on a network and, you know, I'm sort of privileged in the way that when I joined Stanford, I joined the computing center at Stanford, which was, you know, either No. 1 or No. 2 in the country with MIT and they – one of the rules if you worked at the center, was you, you had a, a hard line in your basement that was hardwired into the main computer at Stanford from 30 miles away. Okay, so in those days there was no modem. There was none of that. Mean this was 1969, but my kids grew up with online access to the Stanford computer. And, uh, the idea was you can stay home and, you know, when there is a problem, we want to be able to call you at 3:00 in the morning to work on it. And you can take over the computer at 3:00 in the morning from 50 miles away. This was 1969. Okay, so that's what I've lived with all that time. Now this is what people discover now with their laptop but, um – although they cannot in most cases take,

take control of the network but they, they can control of their environment, and that's, that's a major, you know, it's a major revolution. Now in terms of spirituality, my approach to it was I mean like everybody else I looked at the Rosicrucian groups and so on. Um, Allen Hynek had, uh, belonged to some of those groups some of the early groups in America and actually studied with them. Um, and was, you know, very intent in, in studying that material. The, you know, the classic Rosicrucian material. And very quickly, as I did, moved away from that and there's nothing wrong with – many of those organizations are very well meaning, and they will give you access to teachings that are valuable and I think are the basic Rosicrucian writings, you know, are an illustration of that. I mean they – let's not forget that that's where science came from, you know, in, in England, of course, with the Royal Society emerged from that, those traditions, and those are traditions that give us chemistry out of alchemy and astronomy out of astrology and, and all of that so they – there is a continuity that modern scientists don't want to see but that continuity is to a spiritual base of how do we, uh, both, you know, observe nature but observe it in a sense that we, you also participate in it when you observe it. I mean it, it's almost a ritual act when you observe a star, okay? And it should be. And I think, uh, Hynek and I very much had the same, same thing and we had independently come to the conclusion that which is written in the Rosicrucian writings that there are – the people who do that have to be self-, um, selected. I mean you, you decided that this is what you want to do whether or not there is an organization you're going to join and, in most cases, there is no organization because the organization is at a different level. But and, uh, Dr. Hynek and I very much jumped independently to the same conclusion that if you, if you want to more you know where to go. I mean it's not in, in a book, you know. And, um, the, um, I've always loved the, that, that image, uh, of a, you know, the Rosicrucians when they were asked, you know, what is it – how did you learn all this, uh, they said you have to buy the book of nature. You have to get the book of nature and study it. And, uh, of course people would say how much is it, you know, and where do I get it? And the book of nature is all around you. I mean that is the book. You, but you – there is a certain way to look at it, which is different from what most people do. And that's what that's the key that's the trick. So and, you know, in astronomy it's observing, uh, at the telescope, which fewer and fewer astronomers do now because it's all digital stuff from satellites, and we've lost that, that connection. But not, not everybody has lost that connection. I mean there are still people who have telescopes in their backyard. So it's a long-winded answer to your question. But that's where – to me that's where the spirituality comes, and you can have the same relationship with a computer and certainly with a computer network where you can get on Google and ask a question and you have access to all of those things that are randomly distributed and, um, and then you have to drive it and be prepared for no surprises.

Learned Foote: Um, I have one follow-up question which is that, uh, in most of, most of your work you're not taking the explicit focus on religious organizations like you do in Messengers of Deception, um, it is, it's there as a, a thread through your work, and I'm thinking of, you know, all the way back to people like Mrs. Keech from When Prophesy Fails, the idea that there's this group of people that is, uh, you know, trying to interact in some why with, uh, the UFO phenomenon, um, and, uh, and thinking of someone like John Mack, for example, who took a much like, he wanted to look at, uh, how, um, Shamans were interacting with spirits and how did that play out and connect to the UFO field, and your work doesn't necessarily take that same angle. You're more looking at, uh, reports, um, from, you know, various officials and how do we assess these reports, what are the material responses, but considering the, that, that

religious angle, I'm thinking of people like Mrs. Keech, I'm thinking of even people like Whitley Strieber who, uh, uh, studied Gurdjieff, uh, before doing the work that he did. Is there potentially some connection between, uh, an altered state of consciousness, the kinds of perceptions that become, uh, uh, feasible through religious practice or through intensive meditation, might there be some connection between, uh, uh, UFO perceptions and, uh, these, um, you know, spiritual exercises, so to speak?

Jacques Vallée: Um, yes, and I've, I've, I've become more and more conscious of, of that to the point where with me it's, it's, you know, I'm, I'm trying to develop sort of a methodology is a big, big word, but, um, an approach to cases, you know, I, people think of me as a theorist, but I've spent most of the time, I've spent with this phenomenon was in a, on, on the computer sort of hashing through the data or in the field with the witnesses, and, as, as you know, I think the best example is that, uh, the case of Juan in Argentina, okay? Where, which is the only case in the archives in, in, in the history where, um, the subject was in fact followed and studied when he was 14 and all the way to being an adult, late, late in his late 40s. Uh, and reconstituting sort of the, again, the arc of what happened to him. Uh, the, in, in doing that, in the case of Juan for example, before I, I went there, um, I, I spent 6 months relearning enough Spanish, I was fluent in Spanish when I was 14, but the vocabulary, you know, flies off. I had spent a month in Spain and was, was pretty good in Spanish, and I've, you know, obviously lost it, and so I wanted to regain enough of it to be able to speak with him one-on-one. Uh, not so much that I didn't want, you know, an interpreter to jump in the conversation, but I, I wanted to hear his words and, and sort of process them and be in his linguistic environment and he, in his thinking environment, and uh, and be able to communicate with him at a level of trust that you can only have when you speak the same language. And so that's very much my, you know, preferred methodology when I can now, and I've, with one case that I'm looking at now that I'm writing up and trying to publish, now I, I've taken one other step which I think Paracelsus would have agreed with, of, of actually asking the, the, the landscape and the time to tell me their experience, I mean, the, of, of actually, you know, going there, hopefully in the same conditions when the thing happened, and, and first letting the, letting the setting and the, you know, the, the, the, the time, the weather, the land educate me about, about the thing that happened. Then I can put the witness, obviously, I'm going to, you know, be there with the witness, he's going to tell me where it came from, you know, if there was light, if there was no light, if there, uh, you know, what it did on the ground and everything else. But I, I also want that to, to come from, you know, respect of the setting. Is there, not that there is necessarily anything special about that particular place, maybe the thing could have fallen anywhere, but it didn't, you know, that, this is where it fell, and so I want to know their history, I want to know who else has been there, what they were doing there, you know, was there a town there, was there a market there at some point. Was, was there, you know, what happens when it rains, and those are things that I need to know if I'm really going to understand a, a case that's worth really investigating, I'm really going to go there, and, you know, in some depth. Now that's, that's not exactly a spiritual practice, but, you know, it comes pretty close to it in terms of, you know, respect for the, for the land and for the, the people there, and their relationship to the land. And we've lost that in the United States because, you know, um, most places in the U.S. you, you get there and you ask for the, the name of a street and the, the people there can't tell you the name of the next street, you know, and, and, uh, and it's right behind, you know, behind a couple of trees, and they, they don't know where they are, okay? And, uh, that's very, uh, shocking to people that come from Europe. And, and Aimé Michel

when he came to, to San Francisco, wanted to visit the grave of his aunt who had died in, in the North Bay somewhere, and, uh, his cousin had no idea where the, the old lady had been buried. And he was really shocked at that, because to him he wanted to be there at, at the place. And he came from the Alps where places are very important. So, uh, that's one thing that is, is important when, you know, when I see Americans, not in, I don't use the term in a disparaging way, because I'm American, but when they, they go to places like Brazil or Argentina or Russia, they don't have that concept of the land and their relationship and their history, how people got there. And, uh, so they make gross mistakes in, in, uh, interpreting what the witness is saying, so I'm not sure I'm answering your question, but, you know, I not, not sure how I got here.

Learned Foote: No, I, I really appreciate it, and especially, I spend time, a lot of time in Nepal and talking to Tibetan people, and just thinking about the importance of place, the importance of history, uh, to any time there's sort of a, a conversation that seems to move beyond, you know, modern sense of what is possible, it's deeply connected to place, and –

Jacques Vallée: Yes.

Learned Foote: – it's connected to the landscape, and it's connected to, uh, all these things, um. So, I, I appreciate those connections, um, those connections being drawn. Um, I want to be, to be conscious of, of time, uh, because we have been going for about an hour and 20 minutes. Um, I wanted to, to ask, uh, maybe a quick follow up on, sort of, your experience as you moved outside of the, uh, American framework or even the Western European framework, and you've, you know, you've talked about spending time in South America, uh, looking at research in Russia and so forth. Um, and I'm curious as to, as you took a, a more global perspective, uh, how did that, how did that impact, um, your perceptions of, of the, of the field? Looking beyond the American, um, place

Jacques Vallée: Um, the, uh, of, you know, uh, I live in Silicon Valley. I mean, Silicon Valley is my backyard, um, and I love it, uh, and I know it well, and I know it's a little, it's little secrets, like, after, you know, 40, 50 years, and I, I think it's extraordinarily rich and it's also, uh, you know, a, a way for which the, the, the, you know, a matrix for which you can look at the world in, in ways that are extraordinarily efficient and, and, and clear. At the same time, uh, it, it masks or it makes a lot of other things disappear. There is no history. Uh, I mean, people don't even know their history of the internet that I've tried to preserve some of it and, uh, but it's, uh, it's hard because people assume the internet was built in order to have Facebook. I mean, it, the, uh, I mean, what else can it do? Uh, that, that's important. The, so, uh, at the same time, you know, I, I, I, I go slowly back to Europe or other places two or three times a year, so I have not lost that, that connection, and I can still think in, in that particular way. And the phenomenon is global, and it's not an American phenomenon. You know, the U.S., U.S. is 5 percent of the land mass of, of, you know, the world, the habitable world. So, um, the, the phenomenon at, at its essence, which is what I want to study now, I mean, that's where I want to focus, is extraordinary, and it's not just lights in the sky. It's not just something that flies over the limits, which is extraordinary enough, but it, it's, uh, something that, and I think the only, the only way it has been depicted right on, uh, in the cinema is, uh, you know, in, in close encounters by Spielberg of, of showing, I mean, they are building a runway and they are expecting something to land. And it, it doesn't need to land, you know, it's bigger than the mountain. And, uh, the,

uh, it's not the little lights which fly around, you know, it's a big guy. And I think, uh, it's very difficult for, for us in our technical civilization to imagine something like that, and even the scientists have, have trouble. You know, there are projects, you know, without getting into, uh, personalities and details, but there have been well-funded projects that went back to Brazil with the idea of checking up on what I had published about the, the Brazilian Air Force, you know, facing these things that came out of, uh, of, of the Amazon. And, so, they, they sent competent people. They sent, you know, uh, investigators, uh, military guys, uh, didn't speak one word of Portuguese, and, uh, they went there and they tried to buy their way through, you know, the data. And they came back with essentially nothing. I mean, the, the, either because they, they never really respected the culture where they were, which on the surface looks like an inferior culture to us, but it isn't. And, um, you know, if you were left alone there, you may be American, but you're going to die in 48 hours if you don't know what the local people know, and the only way you're going to, your life can be saved is if they want to save you and they teach you what you need to do to get out alive of certain situations. So, the, um, the naivety with which we, and I, I identify now with, you know, those, those investigators, uh, we approach these other cultures, whether it's Russia or Brazil or Argentina, uh, is, is, is horrible. And, um, I was never completely comfortable in Brazil because I don't speak Portuguese. I've, I've never studied it. Um, uh, I'm much more comfortable in Argentina or in Mexico because I, at least I understand what people are talking about even if I don't understand every word, but I, I get the tone of the, and in most cases I can participate in, you know, at some level. So, they, um, there is a relationship, but, uh, that, and you need that relationship to build trust, and if, if there is no trust, it's not that they will deceive you, they won't try to deceive you but you're not going to understand what they are telling you. And you're not going to understand the – and what happened in Brazil is a, uh, you know, case in point. I mean, for 3 months, there were UFOs. I mean, there is no question that there were UFOs, and it couldn't be anything else. You know, the, something the size of an airliner coming out of the water of the Amazon, all lit up, you know, flying over an island, uh, and this happened again, and again, and again, and again. And the, the people on the island because they, their survival depended on being able to hunt and fish at night for climate condition because you're under the equator and you have to understand all those things; you have to be there to understand that, no, you cannot go out at 2:00 in the afternoon or you'll, you know, you'll be sick, and, and, uh, you won't be able to think, you, you won't be able to move, you won't be able to do any of the things you want to do. And, um, these things were happening at night and people left the island, all the people who could, and the people who were left, you know, so, the, essentially the, uh, Brazilian Air Force being deployed there on those beaches, camping there, and taking notes, and they changed the patterns of all the airlines around the mouth of the Amazon so that anything that flew there was a UFO. I mean, it was just as simple as that. And the, the reason I had, I was able to document this at a particular time was that the people who had been in charge of that task force were still there, you know, in that, uh, Air Force base. And, uh, that Air Force base is, uh, the size of France. I mean, the, the territory it covers. And the man in charge was head of intelligence, and the reason he wanted to talk to me was he wanted to tell his story to somebody. He had read my books before. Some of my, my books have been translated into Portuguese and he had read them, but he wanted to know what was going on in France and if there were similar things to try to understand what had happened to him and to his men during those 3 months when they had total control of the airspace over the mouth of the Amazon. And night after night after night, they were documenting these objects dropping from the sky or coming in and flying over or coming out of

the water. Now, that is, that is a phenomenon, and, and it couldn't be anything else. I mean, this was not mirages. There are no mirages at night over the Amazon, okay? And that come out of the water. So, the, um, those are the, sort of, the extreme cases. There was something similar when, um, um, one of the times, I've gone to Russia six times, but, uh, and one of the times was under official auspices at the beginning of the Gorbachev era where things were open. And so, this was, sort of, the tail end of the Soviet Union merging, reconnecting with its, sort of, Russian identity, and it was extraordinary. And the, the, the cases that they were documenting were, you know, were of that scale. And, um, I don't speak Russian. I can decipher a little bit of Russian if I have to and, with a dictionary, but, um, the, after being there, again, with interpreters and with guides and so on, I could participate in what they were telling me at, at the right level, at the level of trust again. And, uh, again, we were there, um, as, you know, two, two French people, uh, not as Americans, and there were, you know, long, tortured relationship between France and Russia that went back to the days of Tsar. So, that, that was baked into the culture, you know, in spite of all the, the difficulties that happened after that. So, uh, there, there was, uh, that connection, and of course there was also an American connection at the same time, so it was a very rich kind of exchange, but I knew that I was only understanding a couple of levels, and the deeper levels I, I didn't have much access to. But in, in Russia, even through, you know, the, all the things that happened under communism, there was that same sense that, um, Hynek and I had about, you know, the Rosicrucian tradition. I mean, as someone like Kazantsev, uh, Alexander Kazantsev was very much inspired by spirituality, you know. And, uh, he had fought World War II, he was decorated in World War II and that gave him access to, you know, certainly to the, the media and to, and to higher-ups because he was respected as a writer, but what he was writing about was spirituality. And, um, when you, when you ask them, "How come you still have those traditions and they were preserved, under Stalin, I mean, of all things?" But Stalin went to the same monastery as Gurdjieff, okay? So, um, well, and the, well, the answer is they laugh when you ask them that question, and they said, "Well, you, you killed all your witches. We didn't."

Learned Foote: That's, that's great. I love that. That's, um, a really, really interesting way to put it. And going back to the Royal Society, you know, that's sort of, like, um, as that is being founded is when, um, Britain is very intent on killing its witches, so to speak, uh, so it's an interesting aspect of the, uh, the history.

Jacques Vallée: Yes. Well, the aristocrats were capable of, you know, rising above that and, uh, uh, you know, that was the invisible college.

Learned Foote: Mm hmm. Mm hmm.

Jacques Vallée: And, um, uh, Hynek was very much inspired by that. I mean, that's where science comes from. And, uh, I think even the, the English have forgotten that, but, uh, we didn't.

Tim Grieve-Carlson: Jacques, you did, um, you did mention earlier, um, Close Encounters, and I, I think, you know, we'd be remiss if we didn't bring up that you were kind of a major inspiration for this, uh, you know, now obscure, largely forgotten filmmaker, Steven Spielberg, um, and his character, uh, in, in Close Encounters, the, the French UFO investigator. Um, and I just wonder if you could talk about that for a moment. I know that you met with Spielberg on,

on at least one occasion, I think, and I wonder if you could just talk about the occasion and making that film.

Jacques Vallée: We, we met on two, two occasions; there were two. Um, the, the character – there, there was, um, there was a character in the initial script. Of course, all scripts get written and rewritten and rewritten, sometimes, uh, on the fly, you know, in front of the camera. And, and, you know, people take notes and the script is written later. But the, um, the ch, the character, first, was, was an American. Uh, it wasn't a Frenchman. Then, um, Spielberg, uh, became aware of the work of a friend of mine, Claude Poher, who was a physicist and engineer in France who had been inspiring the French government to start, you know, to, to look at that. And then, um, that, so th, that character evolved, and then he had been aware of my work. He told me he had read Anatomy of a Phenomenon when he was a, you know, a, a, a student in, in cinema, and, in fact, had done a movie at that, at that time, in 16 millimeter, you know, uh, sort of inspired by, by that, and there were things in Close Encounters that came out, straight out of, um, Anatomy of a Phenomenon. Like the little light that, and, and the, the road sign vibrating and so on that was actually in Challenge to Science, in one of, one of my books from that era. And so the, uh, so eventually the, uh, character was, final character was based on me, but it, it came through that line of being rewritten three times. The, um, when I, I met with him, that was, that was sort of funny, because the, uh, a, uh, a reporter, you know, brought us together. She was writing an article in, in a, uh, magazine about the, the movie, about Close Encounters, and, uh, she brought us together over luncheon, in Hollywood that time, and, uh, that's when she asked, uh Steven Spielberg if it was true that the character was based on me, and he, uh, told her, um, that was in, in, recorded in her article, so there's no, no question about that part of it. But he told me that, um, he said, you know, "You're, you're a scientist. Maybe you can help me, because I spent the morning at JPL looking for ideas on – because there is, there is a gap in the script. They know that the big mother is coming; that something is coming. They don't exactly know what it looks like, and they don't know where. So they, it's important for them to go meet it. And, uh, as you know, it's going to be Devil's Tower in, uh, in Wyoming, and, uh, but they don't, they don't know that. So they," he said, "at JPL they told me all kinds of scientific things that made no sense, and it was just too technical. I can't use it." And I said, "Well, you know, maybe something very visual and direct would, would work. Like they get a signal and, uh, they get a signal from Point A, and, you know, it points in a particular direction, and they get a signal from Point B, and the two lines intersect, and that's where they should go." He said, "Well, there are two problems with that. One is, it's too long to explain, and No. 2, it's not funny. And it has to be something that, you know, will stay in people's mind." So I thought of, um, the – actually, I have, in, in what I sent you, you know, about the history of, uh, my computing, you know, beginning, there is that cover of Life magazine where the big, the big sphere, okay, I, I remembered seeing that on Hynek's desk. That picture. Okay? With, with three astronomers trying to figure out the orbit of – and Hynek said, "Well, you know, that picture was taken when the Russians launched Sputnik 1, and, and nobody had a way of computing an orbit of a satellite of the Earth." They were, there were programs, there were two programs computing orbits. One was an orbit of a comet, which assumed that the, the Earth was flat, because it's close enough approximation because comets are far away. They are, they are thousands of, you know, of, of miles away, and so the, it doesn't matter, the shape of the Earth doesn't matter. Uh, which is fine, but, uh, when you track the, the, comet, but that, of course, doesn't work for a satellite of the Earth. And the other one was, there was a program computing

satellites of planets, like the satellites of Jupiter, but they assumed that, uh, the Earth, uh, was, uh, reduced to a point, okay? So, or, or vice versa. I don't remember which it was. But in both cases, you, you couldn't use it. So the, uh, when Sputnik 1 was launched, the director of Harvard Observatory was woken up at, in the middle of the night by a reporter from the New York Times asking for a comment. Uh, you know, 'What is your impression? What do you have to say about the Russian satellite?" And he said, "What Russian satellite?" It's 3:00 in the morning. And, uh, they said, "Well, um, uh, listen to the radio." And they rushed to that place which is a lobby of, um, of the, uh, uh, museum, where there was this big sphere, and they were putting a piece of string around, including Hynek, was on the ladder trying to fit it, uh, over places where the satellite had been seen. And that's the way they determined the orbit the first time. I told that to Spielberg and he just burst out laughing. He said, "That's it," you know? "They say, you know, we've got, we've got the, you know, $2 billion of equipment here with, deployed, you know, the intelligence, you know, army intelligence and so on, and, uh, you know, where, where, where is that?" And the, uh, the interpreter of Lacombe, you know, the French guy, says, "Well, I, I used to be, you know, a geographer, and the, the signal we get looks like longitude and latitude, and it, it's up north somewhere, in Wyoming." And he said, "Well, where in Wyoming?" You know, "Get me a map of Wyoming," and nobody has a map of Wyoming. And that's where they break into the museum next door and they bring back the, the sphere, and they look at it, and that's how they know where they have to go. And that, that filled in – I was never paid for that, but, uh, you know, they, uh, that filled in the, the, the hole in the script. And I'm sort of proud of that because it's funny, and it's, it's visual, and it's exciting, and it's funny. But that came directly from Hynek, you know, again. Uh, so small world. Uh, it came from American science being caught, you know, uh, completely unaware of what was going on, and it would be, you know, as you know, it would be a couple of years before U.S. was able to launch its own satellite.

Tim Grieve-Carlson: Yeah, and, I mean, um – that's just such a f – I hadn't, I hadn't, I hadn't heard that story before. That's that, that is really interesting. Um –

Jacques Vallée: It was funny because it brought in Hynek, and I, I had always remembered that picture. It was the cover of, of Life magazine.

Tim Grieve-Carlson: Mm hmm.

Jacques Vallée: With the three astronomers fitting the string around the Earth, you know.

Tim Grieve-Carlson: Yeah. It is, it is kind of a cinematic detail. Um, just a, just a few more questions we got here for you, Jacques. One, um, and also, kind of, speaking here of Hynek, in this earlier phase of your career as a UFO researcher, at times you did, sort of, either, either alongside Hynek, and sometimes in other capacities, you did at times advise governments, um, work with other people who were working with, uh, defense agencies on the UFO phenomenon. You mentioned the, the Nimitz report a moment ago. Um, and following this report, of course, you know, questions surrounding government knowledge, military knowledge of UFOs, these are more popular than ever. And so I wonder if you might just, um, give us your take on kind of, not only these recent articles, um, in the New York Times, but also kind of the, the state of the question right now as, kind of, it's developing, um, with what, um, you know, whether, whether

you want to call it, some people like to call it disclosure, or just sort of the development of kind of more public knowledge of, of military involvement in the phenomenon.

Jacques Vallée: So, um, there are several angles here. You, um, and yes, uh, we, um, um, you know, a group of us are right in the middle of that, um, and, you know, many people have started to work on that. The military encounters are, are interesting, especially when you have something like, you know, the Pacific Fleet being, being involved with, um, a series of objects, um, uh, because the, the military, of course, has sensors that are very, very good. And it also has observers that are very, very good. I mean, those pilots, of course, you know, are highly trained, and they don't panic, and they, uh, they know where they are, and they know their instruments, as well. So you, you get, you would think that you would get a lot of data that would help you, um, find out – well, certainly exclude if it's something known; you'd know it very quickly. If it's something unknown, you'd have the characteristics very quickly. Well, that was certainly true, you know, in, in Brazil. They had 3 months to record what was happening around them, and they had instruments and they had cameras to, to document what was, what was happening. We still don't know what those things were. Um, there have been cases like that in other countries, where aircraft carriers have recalled it. Um, nobody talks about that because nobody knows about those cases, but there have been several cases where foreign navies have recorded things like what the Nimitz recorded. Uh, so it's not new. Uh, it's, um, it's interesting because the, the instruments of the, the planes, including the infrared cameras, were very, were novel, and they were very, very good. And the p, and there were a number of pilots. Um, the, the danger that I see there is, is, is two, twofold. There is a, the, the, the military cases are only 10 percent of the database. You know? Even if you looked at the, the Air Force database, you know, Project Blue Book, uh, with it, you know, 10,000plus; maybe 15,000 cases, um, many of them came from the public, not from pilots. Or it came from people on the ground, or it came from instruments. Um, so, but, but many of them came from the public reporting to the Air Force. The, most of the cases in my files are not military at all. I mean, they come from, and those are more interesting cases, because I, I have access to these people. I can go see them. They take me to the spot; they show me which direction it came from and so on. I can reconstruct that with them, and I can, I can probe into their recollection, into their memory, you know, into their emotions, and, and all of that. So that's, that's, in a way it's richer in another dimension. I don't, I don't have the, you know, the, the, the camera; I don't have the infrared; I don't have all of that. But, um, at the end of the day, we still don't know what kind of thing was flying around the Nimitz. Uh, we don't even know – I mean, there is a memo from the, the people who built the, the infrared camera saying, "You're extrapolating from the instrument we give you, but you're wrong. I mean, the, the instrument doesn't give you the distance; you'll have to get the distance from something else, and, uh, the instrument wasn't designed to track UFOs. It was designed to track sources of heat, like the exhaust of a, of a missile. Or the exhaust of a jet. And so you're extrapolating, and that's fine, but remember, there are limitations to the instrument we gave you." Okay? Um, so the, what happens now is, it can be misconstrued. It can lead us in, in, away, in fact, from, uh, what I think would be of most interest to scientists, um, to the extent that, you know, most scientists would say, well, you know, there are lots of things the military is doing, or foreign military is doing, that are classified. We don't have access to that, you know? I mean, there is lots of stuff. They don't even have access to the, the satellites that record the weather on Earth, you know, for the military, uh, because it records all kinds of other things, and the characteristics of those satellites are classified. So the meteorologists, or the, you know, the weather experts, the climate

experts, haven't had access to it. And some of that is by design, because there was a political will to sort of make people forget about climate change, and those satellites would, you know, would scream planet, you know, climate change on a planetary scale, because l, they look at the whole planet across the spectrum, not just the clouds and rain, okay? They look from the UV all the way to the infrared, to the far infrared, and everything in between. They also look at Xrays; also look at radioactivity. So you have an extraordinarily rich thing that has n, has never been accessible to science. And would tell us about the real history of the planet over the last 25 years, okay? Uh, most universities don't have computers big enough to analyze the data, so you, you would have to bridge a lot of things. So with, with UFOs, we, you know, the, the scientific community isn't quite ready to engage into that, that type of data that comes from the military, especially from military intelligence and from some of those, uh, cameras are still classified. So, uh, it's difficult, and, uh, when you talk about, um, disclosure, you know, I have a problem with that, because what is it we're going to disclose? And, and if you say we're going to disclose that there is a phenomenon that's unknown, well, you know, we did that in 1955. I mean, um, I mean, Michel did that. Uh, Hynek did that. I mean, we, we, we know there's a phenomenon we don't understand, and it's, it's very rich; it's, you know, um, the Bigelow projects did that. I mean, NIDSci, you know, was run by competent scientists, and, and a great business leader, Mr. Bigelow. So, uh, they did that. I mean, it was, it was done by that group, and it's there. Uh, I mean, in the NIDSci advisory board there were two, two of the, um, Apollo astronauts who had walked on the moon, okay? So what else do you need? I mean it's, we've disclosed that. Uh, if people won't listen, it's their, their business. The, so are we disclosing that, uh, that it's a threat? Well, it isn't a threat. I mean, the Nimitz is still, you know, going on its happy way. In fact, during that whole episode, I mean, the, the, the sailors were joking with the pilots, uh, you know. And so, uh, the, the Nimitz never felt that it was in danger because those things were flying around. So either they knew something that the rest of them didn't, or it was just not, you know, not really a threat. There, there were threatening moments, uh, to the pilots. I mean, there is no, no question this was serious. But in terms of the, the big picture, um, it's something that came and went. So it's not, uh, disclosure of anything. Now, there are a number of people that want to use that as a way of, as a channel to disclose what they think it is. And, uh, but that ranges, you know, the gamut, um, from personal beliefs to, um, even scientific theories that these are mirages. I mean, when you talk to the city people, they say, "Well, either they saw balloons, or they saw mirages." Well, I, I, I don't think it's an even fight between a balloon and an F18, but, um, if that's, you know, that's the way I've heard scientists here in Silicon Valley talking about the Nimitz, uh, thing. So, uh, the, we're a long way from disclosure, and there may be, as we know from recent history, there, there may be groups that want to influence a disclosure in their particular, um, way of, you know, thinking about the phenomenon, um, and restrict it to a particular interpretation of what it could be. And, um, uh, essentially a manipulation of the mind of, of people to enforce a particular thing. And one example of that is, you know, one, one thing I've learned about sightings in Russia, um, is, what, that I learned from a skeptic. Because I, I do listen to the skeptics, and they, they, when they know the data – the main problem with the skeptics is that they don't know the data. But the skeptics who have studied the data are, are very valuable, and one of them told me about some of the cases that, in, in the Russian archives, uh, recorded as UFOs were illegal launches of rockets that they disguised as a UFO, and that's why all of a sudden it's in Pravda, you know, it's in the newspapers because they wanted people to think that those lights they saw over the horizon – of course, uh, the base is far from, uh, towns – uh, so they, they see a light that goes up in the sky,

they want them to think that it's a UFO because they are launching, you know, illegal rockets, and, in violation of the SALT Treaties, and the U.S. of course knew that, but the public didn't know that, and maybe it was better for the public not to know that, both in Russia and, and here. So there are all these interpretations that, you know, are – and, okay, uh, I learned something. I said, "Thank you, you know, I didn't know that. I had it in my database as a UFO. Now, um, again, you have to go through those filters, and when you talk about disclosure, um, you know, again, uh, y, you're entering the, a, an area where the words are not well defined.

Tim Grieve-Carlson: Yeah. Jacques, so, um, first, I mean, first of all, that's definitely gonna be my new response the next time someone starts talking about disclosure around me, will be, "Disclose what?" I like that a lot. Um, kind of, so perfect segue into this, what, what, what I think will be our final question – and, again, thanks so much for taking the time to, to do this interview with it.

Jacques Vallée: Oh, my, my pleasure.

Tim Grieve-Carlson: Yeah. Um –

Jacques Vallée: Um –

Tim Grieve-Carlson: – as you point out, the, the terms around this phenomena are, are sometimes either poorly defined, or they have kind of complicated, or in some cases compromised, histories, and with an eye towards, kind of, the historians of the future; the researchers who might be turning to this archive, um, your, your collection, and, and the history of the UFO phenomenon, kind of as our, to conclude, I'd like to just ask, um, what would you like to say to those researchers now? What, uh, what mistakes would you like to kinda caution them against, and what, um, what sort of things would you like to tell them?

Jacques Vallée: Oh, uh, you know, it's, it's, it's not for me to say. I mean, they will come with their own background. They will bring something new to the equation. So I can't presuppose, um – I, I think I, I've done my work of documenting, you know, what could be documented. Uh, in my correspondence with both Aimé Michel and Hynek, you'll see times when we disagreed. Times when we, the conversation almost broke up because we, you know, we were mad at each other, um, because I felt some things should have been done, and they were not done. And, um, or there were interpretations that were missed, and, um, and, uh, and number of ti, all of those times I was wrong, or I was just too young and, you know, uh, too impulsive to tolerate nuances. Uh, and there are lots of nuances. So, uh, I think that, uh, I, I see more the collection for, for those people, especially if they are scientists, as safeguards, you know? I mean, of, because, uh, we keep making the same mistakes again and again and again. And I see people who come into the, you know, I, I've, a very good friend of mine is a brilliant physicist, um, and he says, "Well, all this stuff now, we, we've got these big databases. You put all that into a Google machine of, you know, we have AI now. There's artificial intelligence. You put it into an AI machine, and it will, it will sort out the patterns." Well, I, I'm sure that, you know, you, you put all that into Google and push a button, that, that Google-intelligent machine is going to give you something. The, the problem is that it's probably going to be very, very, very misleading. If, if you had to recruit a, um, you know, a staff of people to work on this, I don't

care where they come from or what PhD they have; it would take 2 years of looking at the records and training them before they could be useful in this thing, or they would have to go around the world, talk to witnesses, make those mistakes that everybody has made, of, you know, planet Venus, and so on, and, and, you know, the fog, and all, all those things before they could form their own unique interpretation of it, and th, this is not something where you can just recruit, you know, uh, three programmers, two AI experts, and couple of psychologists and go. Uh, when, uh, I had that job of building the database for BAASS, which was, you know, the, the second Bigelow project, the, the one that was tied to AATIP, you know, in the Pentagon. Um, I, the, I, I said, "We're going to build a database in Excel." And they said, "Well, what about AI? What about, uh, you know, advanced programming languages?" Well, No. 1, Excel is an advanced programming language. If you, if you really know Excel fully, you can program in Excel. And, No. 2, I can, I can hire Excel experts today, you know? I, they already know it. And the, the first level is just dumb level of populating an Excel spreadsheet with the data. Then we'll build the second level, which is going to be looking for patterns to differentiate, you know, the, quote, the "best" cases to use – that, that was the wrong word, but you know what I mean. The, the important cases from the, the ordinary cases. And then, then we can have something that we can drive under AI. But you have to drive the AI the way you drive a truck. You can't just give it to the AI and say, "Give me a pattern," because the AI is going to go off the rope, or the cliff.

Tim Grieve-Carlson: Well, uh, Lauren, unless you have any other questions, um, Jacque, umm, thank you again for your time this evening. This has been lovely.

Jacques Vallée: Oh, uh, if you transcribe this, uh, I'd love to review it and maybe clean it up a little bit.

Tim Grieve-Carlson: ****.

Jacques Vallée: Because, uh, sometimes better words to use or references that you might want. And then, uh, after we look at it, if you want to do a second, uh, you know, a second iteration, I'm certainly open to that. As you can see with, uh, the computer I'm using, um, we did it over two, two sessions, and that was really useful, because, uh, the questions the second time were not the same ones.

Tim Grieve-Carlson: That sounds great. Yeah, that ****.

Jacques Vallée: So I'm, I'm open, you know, and I'm, thank you for doing this. This is great.

Tim Grieve-Carlson: Sure.

Learned Foote: Yeah. We can, we can definitely create the transcript. I think that'll be a really useful document, and hopefully be, uh, the ground for future conversations. Um –

Jacques Vallée: Okay.

Learned Foote: – this has really been a wonderful, a wonderful treat, and we are, we are so excited we got to sit down with you today.

Jacques Vallée: Well, thank you.

Tim Grieve-Carlson: All right.

Jacques Vallée: Thanks.

Tim Grieve-Carlson: Thank you, ****.

Jacques Vallée: Good night.

Tim Grieve-Carlson: Take care. Be well.

Jacques Vallée: Good night.

Learned Foote: Good night.

Tim Grieve-Carlson: Good night.

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ARMY CONCEPT TEAM IN VIETNAM
APO San Francisco 96243

HELIBORNE ILLUMINATION SYSTEM

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JOINT RESEARCH AND TEST ACTIVITY
Office of the Director
APO San Francisco 96309

REPORT EVALUATION BY DIRECTOR, JRATA

It is extremely gratifying to review the evaluation report of a system which clearly provides improved, or new combat capabilities. Employment of the Heliborne Illumination System, in conjunction with other surveillance systems, has aided materially in interdicting Viet Cong movement during the hours of darkness. The Viet Cong, although harassed by daytime airstrikes, have enjoyed a large degree of freedom during night operations in the past. Wide spread use of this, or a similar illumination system, may have the effect of removing the cloak of darkness which now protects the Viet Cong.

During the time period 5 - 22 September 1965 the Heliborne Illumination System was used on fifteen night combat missions. These missions resulted in 23 sampans destroyed and 25 damaged; four boats and barges were sunk; and it is estimated that over 60 Viet Cong were killed during these attacks. Impressive as these figures are, they still do not accurately describe the potential of this type operation. This was a learning period, and in some cases the system was used for road reconnaissance, rather than for canal and waterway patrol where it has proved effective in restricting Viet Cong night operations. A captured Viet Cong stated that night helicopter operations against river traffic had decreased the mobility of his battalion. Battalion night river crossings which formerly required two hours to complete now require six to eight hours because of additional security precautions.

It is also noteworthy that the system looks extremely good from the cost-effectiveness standpoint. Although it is a cheap adaptation of existing equipment, (local cost of under $500 plus government furnished material valued at approximately $400) it has proved effective in the support of night interdiction and hamlet defense, and in the illumination of helicopter landing zones.

The findings, conclusions, and recommendations of the report are well substantiated, and I concur in them. Priority action should be given to procurement of four Heliborne Illumination Systems for each aviation battalion in the Republic of Vietnam, and two systems for each Division Aviation Battalion organic to US Forces in Vietnam.

Approved:

John K. Boles Jr.

25 October 1965

JOHN . BOLES, JR.
Brigadier General, USA
Director

ARMY CONCEPT TEAM IN VIETNAM
APO San Francisco 96243

FINAL REPORT

HELIBORNE ILLUMINATION SYSTEM

JRATA Project No. 2L-506.0

25 October 1965

Approved:

Hugh E. Quigley

HUGH E. QUIGLEY
Colonel, Armor
Chief

AUTHORITY

Letter, AGAM-P(M) (17 Jul 64) ACSFOR, DA, 31 Jul 64, subject: Army Troop Test Program in Vietnam (U), as amended

CINCPAC Message DTG 130225Z January 1965

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Technical and engineering assistance by the Advanced Research Projects Agency, Research and Development Field Unit-Vietnam (ARPA RDFU-V)

ACTIV is grateful for the assistance and cooperation given by the 119th and 197th Aviation Companies in furnishing aircraft and crewmembers for this evaluation.

PROJECT OFFICERS

Major Richard N. Thrower, Infantry

Major Bud Wallace, Infantry

CONTENTS

FIGURES

I. PREFACE

A. ABSTRACT

The purpose of the Heliborne Illumination System (HIS) project was to determine the operational suitability and concepts for effective employment of such a system in counterinsurgency operations in the Republic of Vietnam (RVN).

The HIS was designed by the Advanced Research Projects Agency, Research and Development Field Unit-Vietnam (ARPA RDFU-V) and fabricated in-country to supplement other methods of illumination in night combat operations. The HIS was flown under varying terrain, weather, and operational conditions on training and combat missions. Fifteen missions were observed by evaluators from the Army Concept Team in Vietnam (ACTIV). Additional data were gathered by interview and discussion with key personnel.

Although the HIS has not been optimized it did provide the US aviation companies a means of illumination for night combat missions, including target identification and engagement, reconnaissance of roads and canals, and illumination of landing zones. Because of the system's simplicity, minimum logistical and training requirements were imposed on the using units.

Prior to the completion of the evaluation, United States Army Vietnam (USARV) concluded that the system was suitable for employment in a counterinsurgency environment and placed a requirement on the Department of the Army, Assistant Chief of Staff for Force Development for funds and parts to build and issue the systems in-country. The system is being produced in sufficient quantities to provide each aviation battalion in RVN with [illegible] HIS.

Generally, 2500 feet absolute was the most desirable altitude for the tactical employment of the HIS. An observer helicopter is normally required for surveillance of relatively small areas, troop formations, weapons emplacements, fortifications and similar-size targets. The observer helicopter follows the HIS just outside the light beam and at an altitude of 300 to 500 feet. A fire team of 3 armed helicopters trails 500 feet to the rear and at an altitude of 1500 feet absolute to provide protection for the searchlight and observer helicopter and also fire power for target engagement.

The HIS evaluated in this project is a satisfactory interim solution for the increased night illumination requirement. Although a step in the proper direction, it is not the optimum solution and research

should be continued to develop a standard aerial illumination system for combat operational use.

B. OBJECTIVES AND METHODS

1. Objective 1 - System Capability

Determine the capability of the system to provide sufficient illumination for night surveillance and operational missions in support of counterinsurgency operations.

To meet this objective, night operations were observed and documented, aircrews were debriefed following each mission, and comments solicited from US advisors.

2. Objective 2 - Tactics and Techniques

Determine tactics and techniques for employing the system in counterinsurgency operations.

The methods used for meeting this objective were the same as those used in objective 1. Questionnaires were used to obtain qualified professional opinion of tactics and techniques from aircrews, commanders, and staff personnel.

3. Objective 3 - Personnel and Logisitcs

Determine the personnel and logistical requirements including the basis of issue of the HIS in RVN.

To meet this objective, an examination was made of company records, interviews were held with aviation personnel, and the performance of operating and supporting personnel was observed and recorded.

C. SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

The Heliborne Illumination System is an effective source of light that provides airmobile companies with an organic capability to conduct limited night illuminated surveillance and operational missions. The tactics for employing the system are basically simple and depend primarily on the type of illumination desired and the type of operation being conducted. Very few logistical problems were encountered during the evaluation. The training of aircrews in the employment of the system required approximately 2 hours. The HIS should be issued as an interim piece of equipment on the basis of four per aviation battalion in RVN. Research should be continued to develop a standard aerial illuminated system. The possible adaptation of the Xenon tank-mounted searchlight as an heliborne illumination system is being explored by ACTIV and a supplemental report will be rendered upon completion of this project.

II INTRODUCTION

A. PURPOSE

The purpose of the Heliborne Illumination System project was to determine the operational suitability and concepts for effective employment of such a system in counterinsurgency operations in the Republic of Vietnam.

B. BACKGROUND

The Viet Cong, using the hours of darkness as natural cover, have successfully conducted night operations over a period of years in the RVN. One method of illumination, Mark 6 aircraft flares, has been only partially successful in providing adequate illumination at night to counter the Viet Cong operations. In July 1964, United States Army Support Command, Vietnam (now USARV) stated than an operational requirement existed for a heliborne illumination system.

Commander in Chief, Pacific (CINCPAC) approved the establishment of a project in two phases. In phase 1, Technical Feasibility, ARPA RDFU-V locally designed and developed a heliborne illumination system. Basic static, flight, and illumination tests were conducted by ARPA RDFU-V to determine operation of the system throughout the desired flight range. Based on the results of these tests, phase II, Operational Suitability and Employment, was warranted. ACTIV was directed to undertake the phase II evaluation.

C. DESCRIPTION OF MATERIEL

1. <u>Light Fixture</u>

The original light fixture tested consisted of a tubular frame so constructed that it could be securely attached to the cargo tiedown points of a UH-1 helicopter and firmly support a cluster of lamps. In addition, it was hinged in such a manner that it could be manually extended from the right cabin entrance and depressed to minimize feedback illumination of the cockpit/cabin area. When not in use, it could be retracted into the aircraft. Illumination was provided by seven 600-watt, 28-volt, sealed-beam lamps of the same type used in the US Air Force C-123 landing light system. These lamps were mounted with one lamp in the center and six equally spaced in a circle around it. The center lamp was rigidly attached to the metal frame. The peripheral lamps could be pivoted radially from the center to enlarge the area of illumination. The lamp mount was also pivoted so that by actuating a lever at the rear of the frame, the whole light beam could be aimed through an arc of about 20 degrees forward and 20 degrees aft of the

vertical and about 35 degrees upward to the right from the vertical toward the horizon. This system weighed 99 pounds (figure 1).

A second system, an improved version of the original and weighing only 66 pounds, was constructed to incorporate a number of minor changes. This system differed from the original in that heat-treated aluminum was used in the lamp brackets and other parts that were subject to stress and vibration, a different arrangement for aiming and focusing the lamps was made, and it was constructed so that it could be mounted in the left door of the cabin to lessen the adverse effect of glare on the pilot. Instead of having an individual switch to control each of the seven lamps, the new system had one simple off-on switch which controlled all lamps (figure 2).

2. Power Requirements

Each lamp requires slightly less than 22 amperes at 28 volts for a total requirement of about 150 amperes. The UH-1 generator is rated at 300 amperes, while normal operating load of the helicopter system is about 100 amperes, leaving enough power for the illumination system.

3. Illumination Capability

Theoretical calculations indicate that from a flight altitude of 2000 feet above the ground with the 7 beams parallel, a circular area 400 feet in diameter could be illuminated with an intensity of 0.735 foot-candles, or 35 to 70 times full moonlight. When the 6 outer beams are spread, a circular area 1200 feet in diameter can be illuminated with 0.105 foot-candles, or 5 to 10 times full moonlight. Similar calculations indicate that at 6000 feet altitude, areas with diameters of 1200 feet and 3600 feet can be illuminated with intensities of 0.062 and 0.012 foot-candles, under parallel and spread conditions, respectively. For comparison, a 60-watt, undirected tungsten lamp at 50 feet distance yields 0.08 foot-candles. Full moonlight is 0.01 to 0.02 foot-candles. (See figures C-1 and C-2, annex C.)

D. SCOPE

1. Definition of the Project

The project was undertaken to determine the capability of the Heliborne Illumination System to provide sufficient illumination for night visual aerial surveillance and other night combat operations as required. Assessment of concepts of employment, adequacy of illumination, and personnel and logistical requirements were made.

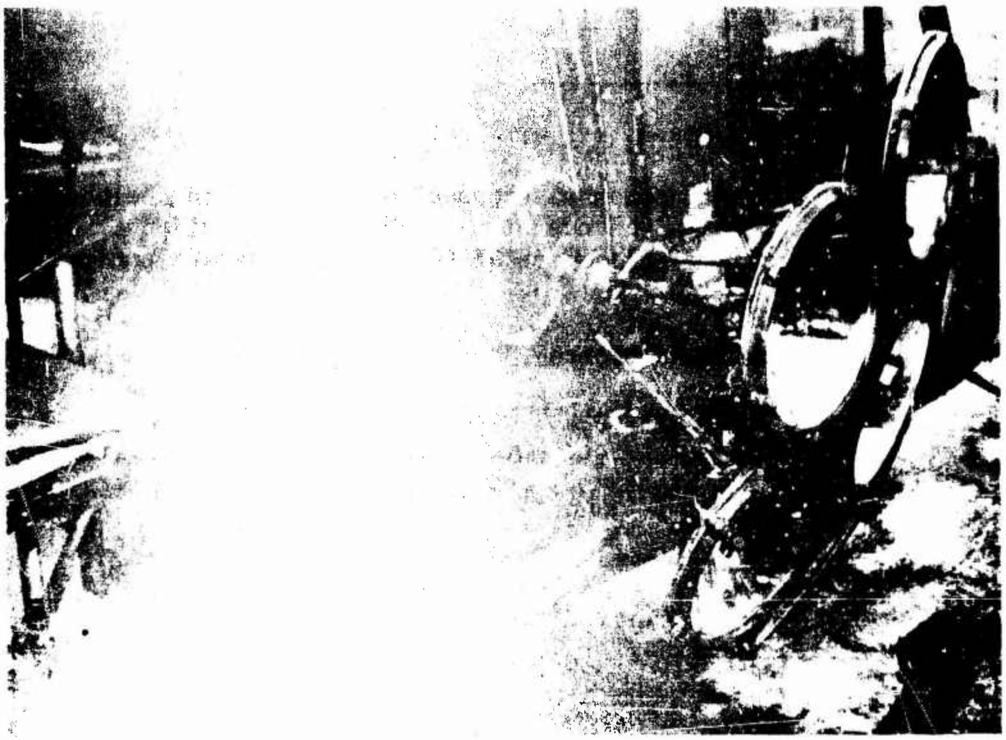

FIGURE 1. Original Heliborne Illumination System.

FIGURE 2. Second, improved Heliborne Illumination System.

2. Setting of the Project

a. Environment

The evaluation was conducted in the Mekong Delta, coastal plains, and central highlands of the RVN. This provided a representative cross section of all types of terrain and weather conditions found in the RVN.

b. Military Elements

The evaluation was conducted during training and combat operational missions that employed elements of the 119th Aviation Company, 52d Aviation Battalion and the 197th Aviation Company, 145th Aviation Battalion.

E. EVALUATION DESIGN

1. Methodology

a. Data Collection Methods

Project officers from ACTIV participated in the majority of the operations when the HIS was used. Discussions and interviews were held with crew members, US advisors, commanders and staff, Air Force liaison officers, and other participating personnel concerning all aspects of the system. The ACTIV project officers served as crew members for both the searchlight helicopter and armed and troop helicopters during the evaluation and flew 15 training and combat missions gathering information and data.

b. Analysis Methods

The analysis was essentially a study of the results obtained from using the HIS in 15 training and combat missions. The opinions of commanders, staffs, and advisors and after-action reports rendered by crew members were evaluated. Observations of operating and supporting personnel and reports of the project officers were also studied to determine the value and limitations of the Heliborne Illumination System.

2. Limitations and Variables

The HIS was issued to the two aviation companies which furnished UH-1 aircraft and crew members for the evaluation, and command and operational control of the system rested solely with that unit. Frequently, the aviation unit's requirement to have a maximum number of aircraft available for daylight missions precluded the use of the HIS at night. In addition, the southwest monsoon season began during the evaluation and low ceilings and visibility at night frequently caused cancellation of

pre-planned HIS missions. At no time during the evaluation were missions conducted solely for the purpose of collecting data.

3. Support Requirements

Project officers and enlisted administrative assistance were provided from ACTIV in-house resources. Temporary duty personnel were not required for the evaluation.

The two heliborne illumination systems used in the evaluation were manufactured locally by a civilian firm, engineer-tested by ARPA RDFU-V, and concept-tested by ACTIV. The systems were returned to ARPA RDFU-V upon completion of the evaluation.

4. Time Schedule

On 10 April 1965, the evaluation plan was submitted for approval and data collection began with a combat mission using the original illumination system.

The second, improved system was delivered on 4 June 1965 and was immediately incorporated into the tests. Data collection continued through 31 July 1965 in the II, III, and IV Corps tactical areas.

III DISCUSSION

A. OBJECTIVE 1 - SYSTEM CAPABILITY

1. Night Surveillance Operations

The HIS was evaluated to determine its capability to provide sufficient illumination for night surveillance missions. Flights were made at various altitudes, from 1500 to 3500 feet absolute, and at airspeeds from 50 to 70 knots. The terrain varied from delta rice paddies to wooded areas and mountains. It was determined that only large, contrasting objects the size of houses could be identified from the searchlight helicopter. This was attributed to the altitudes at which the system was being flown and feedback illumination which produced a halo effect around the searchlight. However, other helicopters following just outside of the light beam and at lower altitudes (500 to 1500 feet absolute) were able to use the light to navigate and readily identify terrain features on the ground.

2. Night Operational Missions

a. Target Identification and Engagement

On pre-planned missions when the nature and location of the target were known, it was possible for the searchlight helicopter to fly directly to the target and illuminate it. If only the general location of the target were known, the searchlight helicopter would proceed to the general area and then begin a search pattern until the target was located. Sufficient illumination was provided for other helicopters flying at a lower altitude (500 to 1500 feet) to definitely identify targets. By flying an orbital pattern the light was maintained on the target and provided sufficient illumination for the armed helicopters to engage the target. The decision to engage was made by the flight leader based on his observation of the target.

b. Night Landing Zone Operations

The Heliborne Illumination System was used to illuminate landing areas for formations of one to five helicopters. In most cases, the system provided sufficient illumination for helicopter crews to identify, approach, land, and take off from the landing zone area. In dusty areas, the helicopter landing light-searchlight system had to be used in order to maintain a horizontal reference through the swirling dust created by the rotor wash. One pilot reported a partial loss of night vision when taking off from an area lighted by the HIS. However, it was determined that this loss was no greater than that experienced when taking off from

an unlighted field using the helicopter landing-searchlight system.

It was found that one HIS provided sufficient illumination to light a landing zone large enough for simultaneous landing of five helicopters. A formation greater than five helicopters landing in a single LZ was not evaluated. However, it was obvious from the amount of illumination provided by the single HIS than a minimum of two systems would be required for formations greater than five helicopters.

3. Findings

It was determined that the system was capable of providing sufficient illumination to conduct night reconnaissance, night target identification and engagement, and night landings and takeoff

B. OBJECTIVE 2 - TACTICS AND TECHNIQUES

1. Night Surveillance Operations

The HIS was evaluated to determine tactics and techniques of employment in counterinsurgency operations. Observations were recorded of how each unit employed the system. No attempt was made by the ACTIV evaluators to influence or dictate how the system should be employed.

Initial attempts at night surveillance employed the HIS on a single ship mission, without observer or armed helicopters accompaning the searchlight helicopter. Feedback illumination from the HIS prevented observers in the searchlight aircraft from identifying anything on the ground except large, contrasting objects.

The tactic that eventually evolved was to employ the HIS at an altitude of 2500 feet absolute. For surveillance of relatively small areas, troop formations, weapons emplacements, fortifications, and similar size targets, an observer helicopter was required. This helicopter, following the HIS just outside the light beam and at a lower altitude (300 to 500 feet absolute), could readily identify small objects and individuals on the ground. The observer helicopter was blacked out; position and navigation lights and rotating beacon were extinguished. A fire team of 3 armed helicopters trailed 500 feet to the rear and at an altitude of 1500 feet absolute to provide protection for the searchlight and observer helicopter and also fire power for target engagement (figure 3).

For surveillance of traffic on canals and roadways and other large targets, the observer helicopter was not required. The armed helicopter following the searchlight could readily identify sampans, vehicles, and other similarly sized targets.

Generally, 2500 feet absolute was the most desirable altitude for the searchlight helicopter. This represented a compromise between

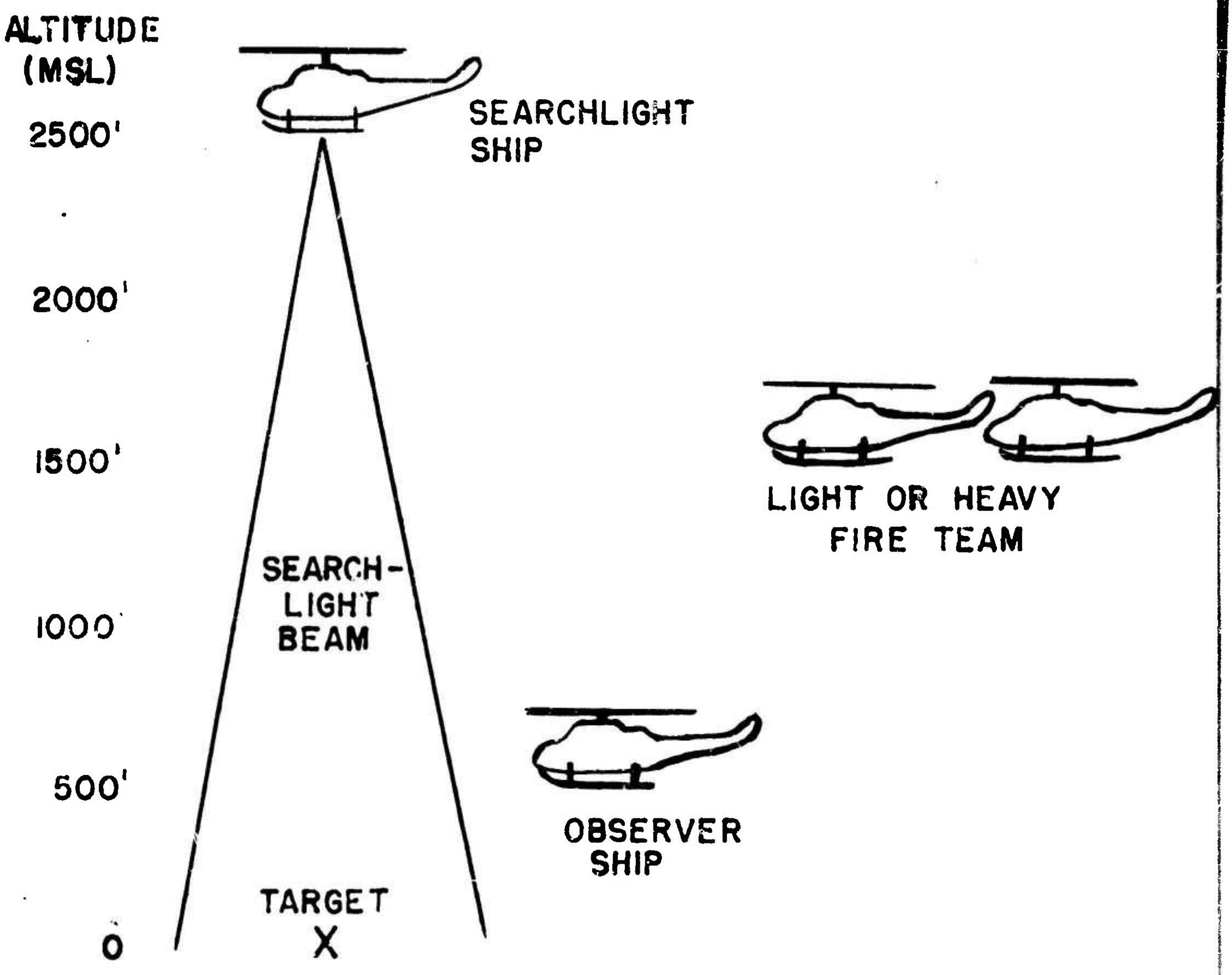

FIGURE 3. Profile view of tactics employed.

sufficient height to reduce vulnerability to small arms fire and enough proximity to produce the desired illumination on the ground. On nights when dust, haze, smoke, or other restrictions to visibility were present in the air, it was necessary to fly the searchlight helicopter at lower altitudes.

2. Night Operational Missions

a. Target Identification and Engagement

The tactics and techniques employed in night operational missions were generally the same as those used in night surveillance. Target location and tentative identification were frequently provided by OV-1B aircraft equipped with side looking airborne radar (SLAR). The HIS and armed fire teams were then vectored to the target location. After the target was identified, and the decision to engage had been made, the flight team leader issued a fire command over the radio. Elements of the fire command were: target, type of weapon system to be employed, direction of attack, and amount of ammunition to be expended. The HIS established an orbital pattern, maintaining illumination on the target throughout the engagement.

The armed helicopters began the target engagement at 1500 feet and ended their firing run at 1000 feet. Regardless of altitude, the firing run terminated prior to reaching the light beam to prevent exposure. During the target attacks the armed helicopters were blacked out. After completing the attack, the rotating beacons were turned on as the helicopters broke away from the target. The flight leader then reported the magnetic heading and altitude to which he was climbing.

If an observer helicopter were employed, the pilot immediately turned away from the light beam at the beginning of the engagement and turned on the rotating beacon so that he could be seen by the armed helicopters. When the observer helicopter was armed, it joined the other armed helicopters in engaging the target. If unarmed, the observer helicopter orbited well out of the target area and at an altitude above the searchlight helicopter.

b. Night Landing Zone Operations

The HIS was flown at various altitudes, from 1500 feet to 4000 feet absolute, to determine the optimum altitude required to provide sufficient illumination for night landings and takeoffs by helicopters. It was determined that the altitude of 2500 feet absolute above the landing zone provided sufficient illumination for the conduct of landings and takeoffs.

Three techniques were attempted to determine the optimum tactics to employ in the illumination of a night landing zone. Flight paths parallel to the landing helicopters and linear and orbital flight

paths above the landing zone were flown by the searchlight helicopter. Of the three techniques, the orbital flight path above the landing zone proved to be most effective. This technique allowed the searchlight crew to maintain the light on a single point and thus produce a more even intensity of light in the landing zone.

3. Findings

The HIS should be flown at 2500 feet absolute while illuminating a target area. This altitude provides a compromise between sufficient altitude to reduce vulnerability to small arms fire and enough proximity to obtain effective illumination of the target area. During periods of reduced visibility it may be necessary to fly at lower altitudes. An observer helicopter flying at 300 to 500 feet absolute may be required for identification of relatively small targets. Three armed helicopters flying below and behind the searchlight at 1500 feet absolute can provide target identification, protection to the searchlight and observer helicopters, and fire power for target engagement. Once the target is identified, the searchlight helicopter should begin an orbital pattern and maintain illumination on the target throughout the operation. For night illumination of landing zones, the searchlight helicopter should be flown in a circular pattern at 2500 feet absolute above the zone.

C. OBJECTIVE 3 - PERSONNEL AND LOGISTICS

1. Personnel Requirements

a. Searchlight Operators

US Army Support Command Vietnam (now USARV) Regulation 95-8, dated 6 April 1965, specified that the minimum crew for a UH-1B helicopter flying combat missions will be a pilot, copilot, a crew chief, and a gunner. In order to minimize the size of the aircrew of the searchlight helicopter, the crew chief was normally used as the searchlight operator.

The simple construction of the system permitted the crew chief to become proficient in manipulating the searchlight in a maximum of 2 hours. The crew chief quickly learned to coordinate his efforts with those of the pilot.

b. Pilot/Copilot

A maximum of 2 hours training in conjunction with the searchlight operator was required for the pilot/copilot team to become proficient in maintaining the light on a target. The pilot flew the aircraft while the copilot observed the effect and placement of the light. Corrections to the pilot and searchlight operator were given by the copilot in order to maintain the desired placement of the light beam. These corrections were given over the intercom system. During periods of radio

congestion, previously agreed upon hand and arm signals were effectively used.

2. Logistics

a. Installation and Removal

Installation and removal of the system presented no particular problems. After a demonstration of the proper installation and removal procedures, the crew chief could perform either task in a maximum of 15 minutes. The system was placed over four cargo tie-down points and secured by four "J"-shaped bolts (figure 4). The electrical cable for the system was fed through the left-hand ammunition chute to the outside of the helicopter and fastened to hard point fittings. The positive cable was connected to the battery terminal of the reverse current relay and the negative cable was connected to the main fuel ground (figure 5).

b. First Echelon Maintenance

First echelon maintenance of the system required no special training for the crew chief and was confined to care and cleaning of the system, lubrication of the moving slides and hinges, and spot painting of worn metal. The only replacement parts required during the evaluation were lamps. Removal and replacement of the lamps required no particular mechanical skill.

3. Basis of Issue

The HIS evaluated in this project should be issued to each aviation battalion in RVN on the basis of four per battalion. Normal operations require only one system but the additional systems would provide illumination for night landing zone operations for formations of more than five helicopters, and enable the units to conduct simultaneous night surveillance missions in different areas.

4. Findings

A maximum of 2 hours of training are required for the pilot-copilot-crew chief (searchlight operator) team to become proficient in employing the HIS. The helicopter crew chief is normally used as the searchlight operator. Because of the simple design and construction of the system, installation and removal is relatively easy and no more than 15 minutes are required for either task. The first echelon maintenance of the system is also simple and is limited to care, cleaning, and lubrication of the system and replacement of burned out lamps. The system should be issued to aviation battalions in RVN as an interim night illumination device on the basis of four per battalion.

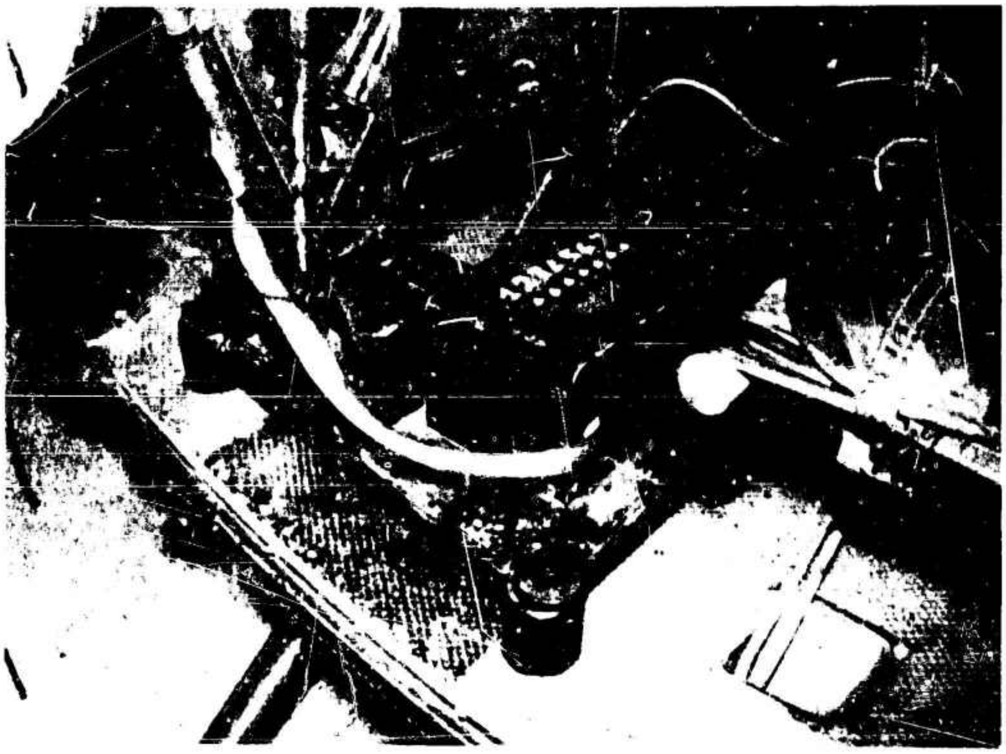

FIGURE 4. View of placement of Heliborne Illumination System inside helicopter cargo compartment

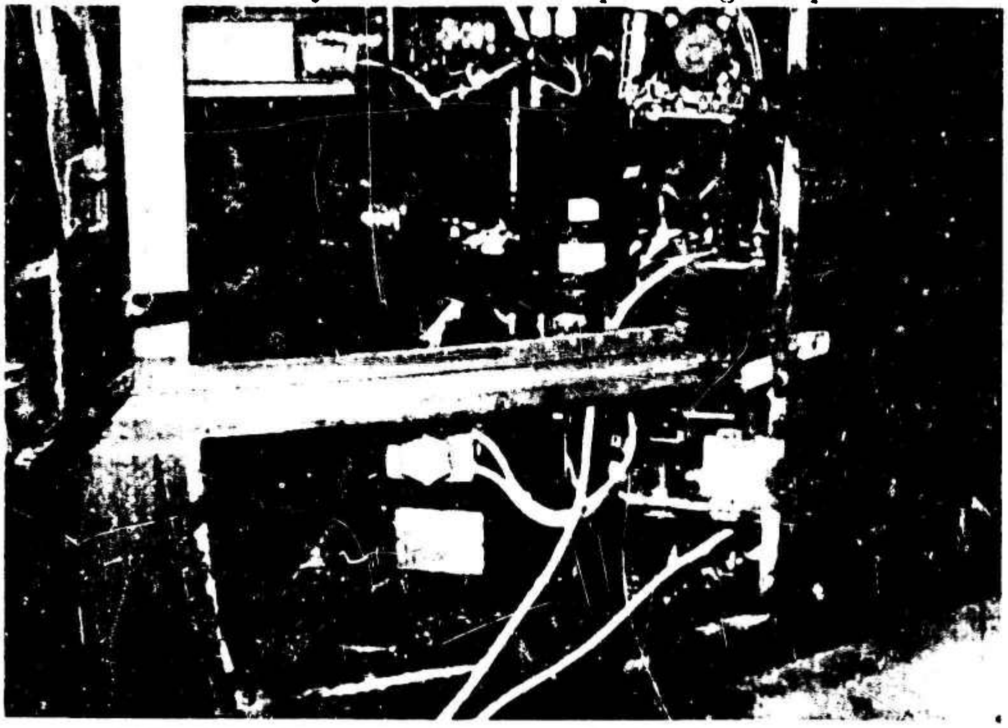

FIGURE 5. View of Heliborne Illumination System electrical connections to UH-1B helicopter

IV CONCLUSIONS AND COMMENDATIONS

A. CONCLUSIONS

It is concluded that:

1. The Heliborne Illumination System is an adequate interim device that provides sufficient illumination for night surveillance and operational missions in support of counterinsurgency operations.

2. The optimum altitude for employing the HIS is 2500 feet above the ground. This offers the best compromise between sufficient altitude to decrease vulnerability to small arms fire and enough proximity to place effective illumination on the desired target.

3. For surveillance of relatively small targets, an observer helicopter will be required. This helicopter, flying without lights at an altitude of 300 feet and outside the light beam, can easily identify targets.

4. A fire team of 3 armed helicopters flying at 1500 feet absolute provides sufficient protection for the searchlight and observer helicopters, and adequate fire power for target engagement.

5. Training of aircrews in the effective use of the system requires a maximum of 2 hours.

6. Because of the simple design and construction of the system, logistical support is minimal.

7. Four HIS per aviation battalion are adequate.

B. RECOMMENDATIONS

It is recommended that:

1. The HIS be procured and used in counterinsurgency operations in RVN.

2. The HIS be issued to aviation battalions in RVN on the basis of four per battalion.

3. Research be continued to produce a standard improved heliborne illumination device to replace the present in-country produced system. (ACTIV is conducting an evaluation of the Xenon searchlight mounted on the UH-1 helicopter. A supplemental report will be rendered upon completion of this evaluation).

ANNEX A

AFTER-ACTION REPORTS

This annex contains brief narrative summaries of some operations with the Heliborne Illumination System. They are not complete studies, but are intended to highlight certain activities during typical operations.

1. TRAINING MISSION IN THE COASTAL PLAINS REGION, 19 APRIL 1965

On 19 April 1965, a night training mission using the Heliborne Illumination System was conducted by the 197th Aviation Company, 145th Aviation Battalion. In addition to the searchlight helicopter, four armed UH-1B's participated in the training. The flight departed from Tan Son Nhut Airfield at 1935 hours and proceeded to Bearcat Range (coordinates YS155990).

The first mission was a point target consisting of a crossroad on Bearcat Range. The searchlight helicopter was flown in a circular pattern above the target at 2500 feet MSL and at an airspeed of 50 knots. Results were excellent. Pilots of the armed helicopters reported the searchlight provided sufficient illumination for them to place effective machinegun and rocket fire on the target area.

The second mission was an area target. The searchlight helicopter flew a linear pattern at 2500 MSL and 50 knots airspeed. Results were the same as for the point target. On both missions, the armed helicopters broke off their firing run before they reached the illuminated area. This prevented them from being exposed by the light.

The third mission was illuminating the airfield at Bearcat. One helicopter made takeoffs and landings on the runway using only the illumination provided by the searchlight. The altitude of the searchlight was varied from 2500 feet to 4000 feet and the airspeed was varied from 0 to 60 knots. Illumination effect on the ground was reported by the helicopter making the takeoffs and landings to be about the same at 2500 feet as it was at 4000 feet. However, the pilot reported a loss of night vision when a takeoff was made from the lighted area. Feedback light from the haze at 4000 feet prevented the searchlight operator from seeing the area on the ground that was being illuminated.

The final mission was to provide route illumination from Bearcat Range to Saigon. The altitude of the searchlight helicopter was 2500 feet and the airspeed was 70 knots. The searchlight provided sufficient illumination enroute for the pilot to navigate and to identify objects on the ground.

Mission returned to Tan Son Nhut at 2110 hours.

2. TRAINING MISSION IN THE COASTAL PLAINS REGION, 21 APRIL 1965

On 21 April 1965, a night training mission was conducted using the HIS. One searchlight helicopter and a platoon of five trooplift helicopters participated in the training. The flight departed from Tan Son Nhut Airfield at 1845 hours and proceeded to Bearcat Range (YS148988).

Formation landings and takeoffs were practiced by the platoon during the waning daylight. As darkness came, the searchlight was employed to light the landing zone.

An altitude of 2500 feet MSL and an airspeed of 60 knots were used during all illuminations. A circular pattern was used by the searchlight helicopter with excellent results. When a linear pattern was used, difficulty was experienced in maneuvering the searchlight over the landing zone at the precise moment the troop helicopters were landing. Additional training and coordination between the searchlight and troop helicopters may resolve the difficulty.

The flight returned to Tan Son Nhut at 2030 hours.

3. COMBAT ASSAULT MISSION IN THE DELTA REGION, 25 APRIL 1965

A combat assault mission employing the HIS was flown on the night of 25 April 1965. The flight, consisting of the searchlight helicopter and five armed helicopters, departed from Tan Son Nhut at 1800 hours and flew to the helipad at Tan An (coordinates XS5465). A briefing on possible locations of Viet Cong rest areas was received from the sector advisor. The flight departed from Tan An at 1945 hours and flew to the first objective area, near coordinates XS545675. An orbital search pattern was made by the searchlight helicopter until a group of thatched huts were observed. These were identified by an ARVN observer as the Viet Cong location. A Mark 6 flare was dropped at the location by an armed helicopter following the searchlight ship. The HIS was ordered extinguished by the flight leader. The suspected area was taken under fire by the armed helicopters using machineguns and rockets.

The second objective area, near coordinates XS497736, was illuminated and ground fire was received. Again, the area was marked with a Mark 6 flare and the HIS was extinguished. The target was taken under fire with machineguns and rockets.

The tactics in both of the above missions were to employ the HIS at 2500 feet in a search pattern of the objective area. One armed helicopter, with an ARVN observer aboard, trailed just outside the lighted area at an altitude of 500 feet. Upon identification of a target, a Mark 6 flare was dropped by the armed helicopter to mark the target and the

HIS was extinguished. The target was taken under fire by the armed helicopters flying at an altitude of 1500 feet behind the first armed helicopter.

The HIS was later used to illuminate a landing area in the vicinity of Thu Thua (coordinates XS535720). The landing helicopter reported excellent visibility provided by the HIS.

The flight returned to Tan Son Nhut at 2115 hours.

After initial illumination of both targets, the HIS was ordered turned off by the flight leader to prevent its receiving ground fire. It has since been requested by the ACTIV project officer that the searchlight helicopter be allowed to orbit an identified target and illuminate it during the firing runs by the armed helicopters.

4. NIGHT RECONNAISSANCE MISSION IN THE CENTRAL HIGHLANDS REGION, 22 MAY 1965

A flight consisting of the searchlight helicopter and two armed UH-1B's departed from Holloway Army Airfield at 2030 hours, 22 May 1965. The mission was night visual reconnaissance south along Route 14. Ten minutes were spent in the immediate area of the airfield to provide the aircrews an opportunity to practice in the use of the searchlight. One practice gunnery run was made on a simulated point target.

Route 14 south of Pleiku was identified with the aid of the searchlight and the reconnaissance mission was undertaken. The altitude of the searchlight was varied between 2000 and 3000 feet absolute because of the low cloud conditions along the route. After approximately 5 minutes of reconnaissance, the flight was directed by the battalion combat operations center (COC) to proceed to a point 1000 meters north of the airfield to investigate a suspected target picked up by ground radar.

A linear search pattern was established in the described area and was continued for 15 minutes. No sightings were made. The flight was informed by COC that the target had disappeared from the radar, and was directed to resume reconnaissance of route 14.

Initially, some difficulty was experienced in keeping the light beam on the roadway. After 5 to 10 minutes, the crew worked out their system of commands and adjustment of the light, and no further difficulties were encountered.

The armed helicopters flew at an altitude of 1000 feet absolute. The crews reported excellent visibility, and stated that the system provided sufficient illumination for them to identify individuals along the roadway.

No suspicious activities were sighted and the flight returned to Holloway Army Airfield at 2200 hours.

5. COMBAT ASSAULT MISSION IN THE COASTAL PLAINS REGION, 4 JULY 1965

A combat assault mission was flown on 4 July 1965 using the HIS. The 25th Division had requested an OV-1B (SLAR) for target acquisition along the Occidental and Oriental Rivers in their area, beginning at 2330 hours on 3 July. The HIS and a heavy fire team of armed UH-1B's were requested to be on stand-by alert at Tan Son Nhut. The heavy fire team consisted of two UH-1B's armed with the M-6 armament system (four 7.62mm machineguns) and one UH-1B armed with the XM-3 armament system (2.75-inch rockets).

The OV-1B was not available until 0045 hours on 4 July because of mechanical trouble. At 0120 hours, the OV-1B reported moving traffic on the Occidental River. At 0125 hours, the 25th Division ordered that the HIS and armed UH-1B's scramble. The flight departed from the airfield at 0135 hours (reaction time: 10 minutes from alert to liftoff) and proceeded directly to Duc Hoa. Over Duc Hoa the flight was directed to coordinates XS509674, northwest of Tan An, where the OV-1B had reported the moving targets on the river. Arriving at this location, the HIS was turned on and four sampans were observed. All four were tied up to the shore and were showing lights. A search was made of the immediate area but no moving traffic was observed. A search was begun up the river to the northwest. At coordinates XS504704, five sampans were observed moving in mid-stream. The target was illuminated and the armed UH-1B's engaged it. All five sampans were hit and two were reported sunk. Ground fire was received from coordinates XS4972. All ordnance was expended by the armed helicopters in suppressive fire in this area.

The tactic employed in this mission was to have the HIS fly at 1500 feet absolute and the armed helicopter at 1800 feet absolute. No observer ship was used.

6. COMBAT ASSAULT MISSION IN THE COASTAL PLAIN REGION, 16 JULY 1965

A combat assault mission was flown 16 July 1965 using the HIS. The operational requirement, target acquisition method, and target engagement remained the same as that previously used in conjunction with the OV-1B (SLAR). The fire team was composed of one UH-1B with M-6, one UH-1B equipped with two CBU-14B's (dispensers loaded with 114 BLU-3/B fragmentation bombs), and one UH-1B with a combination XM-3/M-5. The XM-3 in this combination carries only 24 to 36 rockets. The M-5 armament subsystem is an area fire weapon specifically designed for helicopters. It consists of: the M-75 launcher (gun) in a nose-mounted flexible turret containing elevating and azimuth drives; and a sighting station. The M-75 grenade launcher is an air-cooled, electric motor driven reciprocating barrel, 40mm, rapid firing weapon capable of launching fragmentation type

projectiles. The HIS was mounted in an armed ship, making a total of four armed aircraft.

The OV-1B (SLAR) reported a target on the Occidental River at coordinates XS438760. The HIS was turned on and five sampans were observed and taken under fire by the M-3/M-5 UH-1B. The rocket run was only partially successful and it was decided to use the CBU-14. A target engagement run was made employing the BLU-3 from the right dispenser; the left dispenser misfired. The run was very successful, resulting in four sampans sunk and one overturned. The team returned to Tan Son Nhut to re-arm and re-fuel. The misfired dispenser was moved to the right side to see if this would correct the malfunction.

The team departed the second time and was vectored back to the Occidental River, coordinates XS473708. The HIS was turned on and a moving target, a 30 to 35 foot motor launch, was located and tracked with the HIS. The rocket ship made a firing run and expended about three quarters of its load. The launch was hit and overturned following which approximately 30 to 35 VC were observed in the water. The CBU-14 was tried but again misfired. The M-5 was employed and also failed to fire. The door guns were then used to engage the swimmers. The HIS was extremely effective as it allowed the gunners to place accurate fire on the target of VC swimmers. It was estimated that all of the VC were killed.

The team departed from this area and returned to the original target at XS438760. The overturned sampan was still floating and as the team arrived, small arms fire was received from the south bank of the river. A .50 caliber machinegun was also firing from XS440771 and the rocket ship expended the remainder of his load on this target. The HIS was turned off and the HIS UH-1B reverted to the armed role. The .50 caliber machinegun was engaged and neutralized by the HIS UH-1B using 2.75-inch rockets. The remaining ordnance was expended over the area south of the river and the team returned to Tan Son Nhut.

7. COMBAT ASSAULT MISSION IN THE COASTAL PLAINS REGION, 19 JULY 1965

At 0145 hours on 19 July 1965, four armed helicopters of the 197th Aviation Company, with the HIS as the lead ship, were scrambled to engage Viet Cong night traffic on the canals South of Duc Hoa. Five minutes after takeoff the pilot of the fourth aircraft advised the flight he had lost his engine oil pressure and was starting an emergency descent. Because a high overcast blocked the moon, the terrain below was an indistinguishable black void that revealed no safe landing area. In the short seconds it took the stricken helicopter to autorotate to the ground, the HIS ship had swung back and illuminated the area so that all obstacles could be seen and avoided. The stricken ship, with the aid of the searchlight, was able to make a safe landing in a rice paddy avoiding the paddy dikes that unseen, could have been disastrous to the aircraft and crew.

The crews secured the area and a maintenance team worked throughout the night to replace the engine. A few hours later the aircraft was flown to its home base at Tan Son Nhut.

ANNEX B

SETTING OF THE EVALUATION

1. ENVIRONMENT

The Republic of Vietnam (RVN) occupies a crescent-shape area of about 67,000 square miles on the southeastern edge of the Indochina Peninsula. Although only 45 miles wide at the 17th Parallel, its demilitarized northern border with the Democratic Republic of Vietnam (North Vietnam), it has a seacoast of 1,500 miles on the South China Sea and Gulf of Siam, and western borders with Laos and Cambodia of about 900 miles. The land borders are poorly defined and drawn through difficult and inaccessible terrain.

a. Terrain

There are four distinct geographical regions: The highlands located in the north and central portion, the plateaus of the central highlands, the coastal plain, and the Mekong Delta in the South. See figure B-1.

The northern two-thirds of the RVN is dominated by a chain of broken mountains and rugged hills extending in a northwest-southeast direction and terminating on the northern edge of the delta plain about 50 miles north of Saigon, the capital. The area is characterized by steep slopes, sharp crests, narrow valleys, and dense vegetation. It is sparsely populated, mainly by primitive and nomadic tribes, and it contains few roads or trails.

The central highlands adjacent to the Laos-Cambodia border contain extensive plateau areas. Here, the mountains give way to more gently rolling terrain. The northern plateau is covered by almost impenetrable tropical forests and jungles, which often have two dense overhead layers of foliage at heights of about 40 and 125 feet. The southern portion is typical savannah country, with large open expanses covered by tropical grasses and open forests. This region is more heavily populated than the northern highlands and has more roads and trails.

The coastal plain, varying from 10 to 25 miles in width, extends from the 17th parallel to the Mekong Delta. At several places mountain spurs jut out to the sea, cutting the plains into a series of compartments roughly at Mui Dinh, Mui Ke Ga, Quang Ngai, Da Nang, and Hue, north of which the spurs become more frequent. The area is characterized by sandy beaches and dunes, backed up by rice fields, fertile areas, and marshes extending to the mountains. It contains many small cities.

The southern third of the country is part of the large delta

FIGURE B-1. Geographical regions, RVN.

plain formed by the rivers Hau Giang, Mekong, Vam Co, Saigon, and Dong Nai. The Hau Giang flows directly to the South China Sea. The huge Mekong splits into four branches, and the Vam Co and Dong Nai enter the Saigon before reaching the sea. In addition to these major tributaries, the area is cut by a number of smaller streams and a dense network of canals. The plain is relatively flat with few points exceeding an elevation of 20 feet above sea level. It is a very fertile area with more than 9,000 square miles under rice cultivation. Drainage is effected chiefly by tidal action, with the difference between ebb and flood as much as ten feet in some areas. The southernmost tip of the delta, known as the Ca Mau Perinsula, is covered with dense jungle, and mangrove swamps stand at the shoreline and on river estuaries. The eastern portion of the delta plain is heavily forested. The Plain of Reeds, a large marshy area covered with tall reeds and scrub trees, is located in the center of the delta region adjacent to the Cambodian border. During the rainy season, a major portion of the entire area is completely inundated.

b. Climate and Weather

The climate is hot and humid, subtropical in the north and tropical in the south where the monthly mean temperature is about 80 degrees Fahrenheit. The annual rainfall is heavy in most regions and torrential in many. It is heaviest at Hue which has an annual average of 128 inches. The low of 28 inches at Mui Dinh, a small cape on the eastern coast some 62 miles south of Nha Trang, results from the presence of hills in the area. At Saigon, rainfall averages 80 inches annually. See figure B-2.

Seasonal alternation of monsoon winds profoundly influences the weather throughout the year, although geographical features alter patterns locally. The winter monsoon blows generally from the northeast from early November to mid-March and often brings floods to the northern portion of the RVN. This is the period of the dry season in the delta, which usually lasts from December through March. The winds begin to shift in March, and with the exception of the coastal plain, high temperature and humidity prevail in all of the RVN from April to mid-June. The summer monsoon blows generally from the southwest from mid-June to late August or early September, bringing to the delta region heavy and frequent rains, high humidity, tropical temperatures, and maximum cloudiness. Mountains cause clouds to pile up and deposit moisture before the clouds reach the coastal plain or the northern highlands, which areas are dry during this period. In September the winds begin to shift again, and the coastal plain receives its maximum amount of rain and cloud cover, including severe tropical storms and typhoons.

c. Communications

Roads throughout the RVN are few in number, poorly cared for, and narrow. Road travel to major areas in the north is often stopped

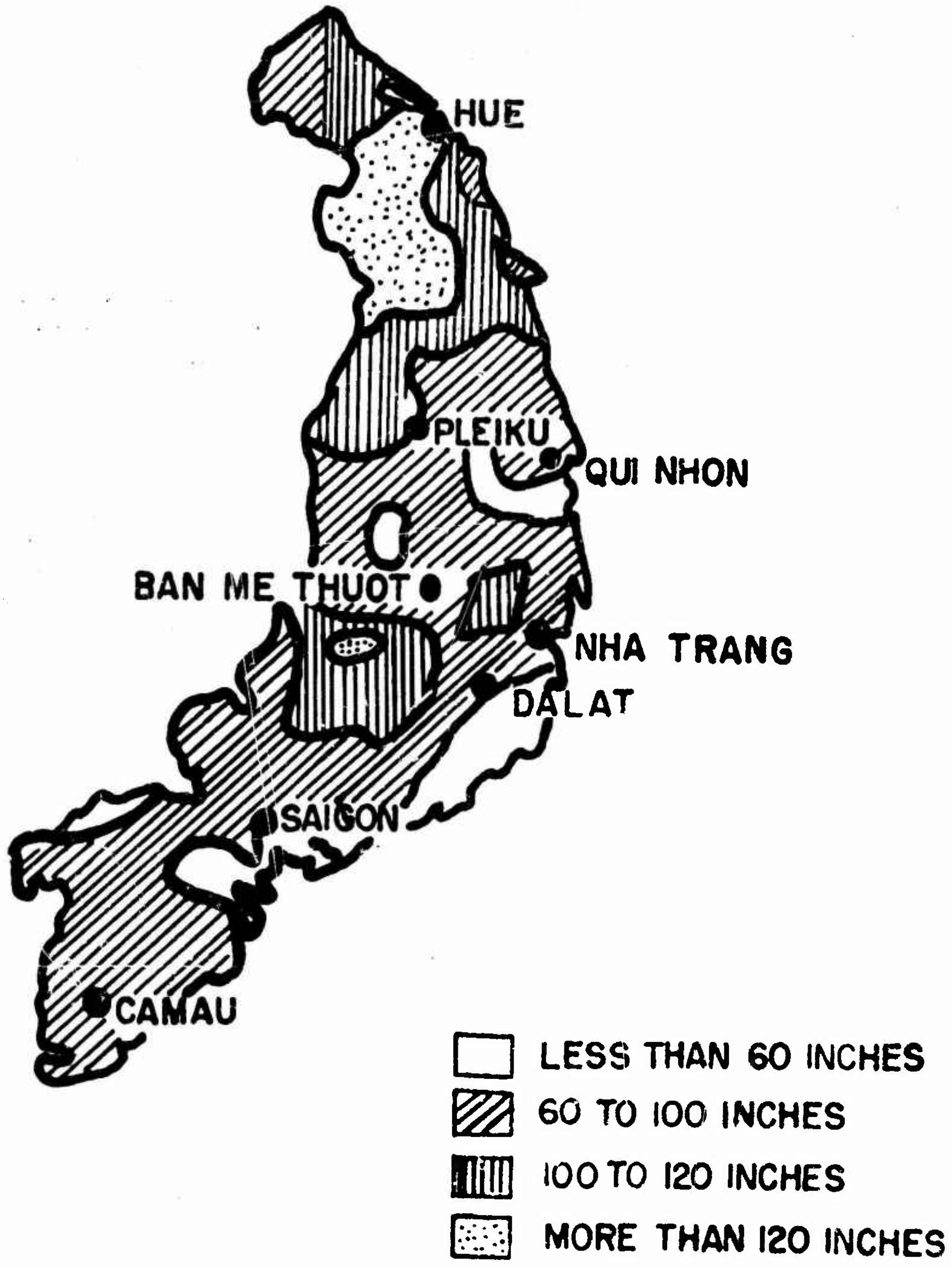

FIGURE B-2. Annual precipitation, RVN.

completely when bridges and narrow places are destroyed, either by natural causes or the Viet Cong (VC). In the delta region, 2,500 miles of navigable inland waterways ease somewhat the communication burden placed on the 1,200 miles of primary and secondary roads in the region.

A single-track, narrow gauge railroad connects Saigon with the northern provinces by way of the coastal plain. The system and equipment is old and frequently damaged by the VC.

There is no wire telephone communication among the major centers of population. What radio telephone service is available is at the mercy of the often unstable atmospheric conditions over the RVN. Telephone equipment used in major cities is antiquated or makeshift.

In effect, rural areas are virtually isolated. It is not unusual for a VC act of terrorism or sabotage to take place in an outlying delta area and be reported in Saigon a week or more later. Most incidents accounted for take at least two or three days to get into the situation reports to Saigon.

d. Popluation

The RVN has a population of approximately 15.7 million, with an average density of 234 per square mile. The highland region is generally the least settled of the geographic areas of the RVN, and the coastal plain contains the most people. About 90 percent of the people live on the 13 percent of the land best suited for rice cultivation: the delta and the small river basin of the coastal plain.

Racially, the population is composed of 85 percent ethnic Vietnamese, 6 percent Chinese (who have established a great influence on the economy of the RVN), 5 percent Montagnard (the nomadic aboriginal tribe people living in the highlands), 3 percent Khmer-Cham (of Cambodian descent), and 1 percent European, Indian, and other small groups.

Religiously, about 80 percent profess Buddhism, about 10 percent profess Catholocism, and the rest profess Muhammedanism, Hinduism, Protestantism, Cao Daism, or Hoa Haoism (two local sects).

Socially, there is an upper class composed of old mandarin families, landed gentry, government officials, professional men, intellectuals, clergy, and wealthy businessmen; an urban middle class of civil servants, teachers, and small businessmen; and a lower class, mainly composed of farmers, but with a growing group of urban workers. Mobility upward within the structure is possible but difficult, especially up from the lowest.

Vietnamese culture is based on traditional Chinese customs and has been profoundly influenced, especially among the upper class

living in the cities, by the French. Most rural Vietnamese continue to follow the traditional way of life. The great divergence in racial, religious, social, and cultural structures has produced continued strife and tension among the people who belong to the various groups. There seems to be no evidence of a permanent stabilizing force available within the Vietnamese society to control conflicting elements.

The Vietnamese have a deep and traditional belief in destiny and man's inability to change the natural order of events. This concept, reinforced by religious beliefs, results in a high valuation of the virtues of stoicism, patience, and endurance. The Vietnamese are proud of their ethnic traditions and hold themselves superior to ethnic minorities in the RVN and to the peoples of neighboring countries.

Most of the people living in the countryside, who make up 90 percent of the population and who provide the main targets for the VC, care neither for the government in Saigon nor for the VC. They want to be left alone to grow their corps, raise their families, have a tranquil old age, and die traditionally.

2. MILITARY ELEMENTS

a. Friendly

Units providing helicopters and aircrews for the evaluation of the HIS were selected primarily for their area of operation, the II and III Corps areas. This provided a representative cross section of all types of terrain and weather found in the RVN.

(1) Units

(a) 119th Aviation Company, 52d Aviation Battalion, Pleiku, RVN.

(b) 197th Aviation Company, 145th Aviation Battalion, Tan Son Nhut airfield, RVN.

(2) Missions

(a) The 119th Aviation Company provided airmobile support for the II Corps area.

(b) The 197th Aviation Company provided armed helicopter support for the III Corps area.

b. Enemy

It is a well-documented fact that the Communist apparatus in the RVN is an extension of the Communist party of North Vietnam, and that

direction and materiel and personnel support is received from the North. Supreme authority in the VC political and military organization in the RVN is the Central Office South Vietnam located in Tay Ninh Province near the Cambodian border. Subordinate thereto are four military regions and one special zone (corresponding roughly to the capital area), each of which has a subordinate series of provincial, district, and village-commune party committees.

(1) Units

The VC military force can be divided into 3 operational categories: main force, local force (together about 35,000 troops), and militia units (60,000 to 80,000 soldiers). The main local force units are controlled by province and district committees. They are well-organized, and the personnel are well-trained and well-equipped. Militia units are full and part-time local armed groups responsible to district, village, and hamlet authorities. Personnel of these units are used frequently as intelligence gatherers, porters, or as reinforcements for main and local force units. They may replace losses in the local forces.

A VC battalion is planned for 400 to 500 men, but in reality may consist of as few as 250. A company averages 100 men, and a platoon about 30. Personnel may be acquired voluntarily, by kidnapping, or by impressment using blackmail or threats of violence. There is evidence that large numbers (a total of about 45,000 in four years since 1960) of native born North Vietnamese have infiltrated from North Vietnam through Laos into RVN.

Viet Cong forces are in general lightly equipped and have a commensurate degree of cross-country mobility. In addition to individual weapons, they have a large number of automatic weapons, and light crew-served weapons. The large units are equipped with mortars and recoilless rifles. Supplies are obtained through capture, local procurement, taxation, and infiltration. Food staples such as fish, rice, and manioc are readily available.

(2) Capabilities

Because of support rendered by the country people, familiarity with the area, lack of responsibility for life and property, and the nature of guerrilla organization, equipment, and tactics, the VC are able to move virtually at will throughout much of the RVN. They are able to exploit as necessary the differences in race, religion, class, economic condition, and cultural background of their targets. They have a well-developed intelligence system, good discipline, and an usually effective security system.

Viet Cong military operations have the advantages of

speed, surprise, deception, and infiltration. Training, accomplished in small, local areas by well-indoctrinated cadre, probably emphasizes selection of the most vulnerable targets, night operations, movement as small units until concentration is required, terrorism and propaganda, use of weapons, employment of terrain and weather, and infiltration. The VC objective is not, at the present stage of their insurgency, to hold terrain, but rather to inflict losses on government forces, to capture weapons and material, and to convince the people that the government in Saigon cannot protect them and will eventually be defeated.

(3) Limitations

Viet Cong limitations stem from their need for strong security and the largely clandestine nature of their activities. Although the people among whom they live afford them a high degree of protection, active and passive, force must often be used, and support based on threats and fear endures only as long as pressure is brought to bear. Primitive living conditions add to the strain of avoiding government troops until the right moment. The VC are vulnerable to air and artillery attack, and less so to armor attack. Limited logistical capability, lack of communications, and insufficient medicine are other weaknesses.

ANNEX C

ARPA RDFU-V INTERIM REPORT

This annex contains a copy of the Interim Report of Evaluation, Heliborne Illumination System Study (JRATA Project 2L-506.0) rendered by ARPA RDFU-V.

ADVANCED RESEARCH PROJECTS AGENCY
RESEARCH AND DEVELOPMENT FIELD UNIT
APO San Francisco 96243

RDFU-V 1 June 1965

WED:rks

SUBJECT: Interim Report of Evaluation - Heliborne Illumination System Study (JRATA Project 2L-506.0)

TO: See Distribution List

1. References:

a. RDFU-V letter serial 390 dated 22 July 1964 with indorsement of Hq, USASC-V.

b. JRATA letter serial 4801, subject: Project Proposal - Heliborne Illumination System, dated 25 November 1964 with one inclosure (evaluation plan) and first indorsement by Hq, USMACV.

c. RDFU-V letter serial 578, subject: Battlefield Illumination, dated 17 October 1964, with three indorsements.

2. Authority: CINCPAC message DTG 130225Z January 1965.

3. Purpose: The purpose of this project is to conduct a study of the required design characteristics for obtaining satisfactory battlefield illumination from a heliborne system.

4. Background:

Viet Cong night operations have created a continuing requirement for illumination. Since the insurgent uses all possible concealment, night provides a natural environment for him. An adequate illumination capability is essential not only for Vietnamese operations, but for any

counterinsurgency effort. This requirement is now met by use of the Mark 6 flare which is normally launched from a C-123 flareship. These flareships are not always available when required, nor is it reasonable to use them for every illumination requirement. It was suggested that a hand-held searchlight be mounted in helicopters in order to provide a lighting capability which would be organic with the helicopter units. A system of this type would provide a limited lighting capability to supplement the C-123 for lesser illumination requirements. By reference 1a, the US Army Support Command, Vietnam, stated the operational requirement for such a system and proposed fitting the light on a flexible mount and tapping power from the helicopter electrical system. There was an immediate need to study the illumination capability of such a system and its adequacy with respect to the needs for aerial surveillance and for assistance to our ground forces. Design of a lighting system with these characteristics was undertaken by the OSD/ARPA R&D Field Unit. Approval was obtained from the Army Materiel Command, 3rd Indorsement reference 1c, for the installation of this system in the UH-1B. An important criterion in the design was the development of a system which could be manufactured locally rather than to attempt the development of a system using the most modern techniques of illumination. In this way, it was possible to obtain a test device with the minimum delay and, at the same time, have the capability to rapidly produce the devices for use in the operational units if this proved desirable. It is believed that at least one year has been saved by following this development philosophy. The evaluation is being conducted in two phases, the first phase being a feasibility study by RDFU-V. Based on the results of Phase I, ACTIV would conduct Phase II, an operational suitability and concept evaluation. This interim report presents the results of the Phase I evaluation.

5. <u>Description of Materiel</u>:

a. <u>Light Fixture</u>: The heliborne illumination system consists of a tubular frame so constructed that it may be securely attached to the cargo tiedown points of the UH-1B helicopter and will firmly support a cluster of lamps. It is hinged in such a manner that it may be manually extended from the cabin entrance and depressed so that there is no feedback illumination of the cockpit/cabin area. When not in use it may be retracted into the cargo compartment, allowing the cabin door to be closed. Illumination is provided by seven 600-watt, 28-volt, direct-current, sealed-beam lamps of the type used in the USAF C-123 landing light system and produces 2.7 million candle power. The lamps are mounted with one lamp in the center and six equally spaced in a circle around it. The center lamp is rigidly attached to a metal frame. The peripheral lamps may be pivoted radially from the center to allow for concentration or diffusion of the area of illumination. The lamp mount is also pivoted so that by actuating a lever at the rear of the frame the whole light beam may be aimed through an arc of about 20 degrees forward and 20 degrees aft of the vertical and about 35 degrees about the longitudinal axis of the helicopter from the vertical plane toward the horizon. The entire system weighs 99 pounds.

b. Power Requirements: Each lamp is normally rated at slightly less than 22 amperes at 28 volts for a total calculated requirement of about 150 amperes. The UH-1B generator is rated at 300 amperes, while the normal operating load of the helicopter system is about 100 amperes, leaving enough power for the illumination system. The electrical load analysis is contained in Appendix A. The lamps are wired for individual selection in order to enable the variation of illumination intensity and electric power loads. Each of two rotary switches selects power to three of the peripheral lamps and one toggle switch operates the center lamp. On the final design the lamps will be individually protected by circuit breakers and one toggle switch will provide the power source for all lamps.

c. Illumination Capability: Theoretical calculations indicated that from a flight altitude of 2000 feet above the ground with the seven beams superimposed, a circular area 400 feet in diameter can be illuminated with an intensity of 0.735 foot-candles. When the six outer beams are spread, a circular area 1200 feet in diameter can be illuminated with 0.105 foot-candles. Similar calculations indicate that at 6000 feet altitude, areas with diameters of 1200 feet and 3600 feet can be illuminated with intensities of 0.062 and 0.012 foot-candles, under parallel and spread conditions, respectively. Details of these calculations are contained in Appendix B. For comparison, a 60-watt, undirected, tungsten lamp at 50 feet yields 0.08 foot-candles. Full moonlight is 0.01 to 0.02 foot-candles.

6. Discussion:

a. Preliminary Tests: This interim report covers the period 1 February to 10 April 1965. The illumination system was fabricated by Societe Anonyme de Mecanique Industrielle et de Construction (SAMICO) and delivered to OSD/ARPA RDFU on 1 February 1965. Upon receipt of the equipment, electrical tests were performed and the system was found to be satisfactory. The system was installed in a UH-1B helicopter to determine that it would attach securely and that the control devices were adequate. It was determined that one man could install the system in 15 to 20 minutes and remove it in approximately 10 minutes, with no modification being required of the helicopter.

b. Basic Flight Tests: Initial flight tests were performed during daylight hours to determine if any helicopter stability and control problems would be encountered from operating the system. A slight yaw tendency was evident during extension and retraction of the searchlight; however, this was easily countered by appropriate application of anti-torque pedal. The helicopter was flown through all normal maneuvers and practice autorotations; no adverse handling characteristics were noted. Maximum indicated airspeed was 85 knots. Throughout the operating envelope the searchlight operator was able to operate the focusing and aiming controls. The helicopter electrical loadmeter indicated 15 percent of rated generator power with normal system turned on; with the light on, the loadmeter indication was 60 percent, or approximately 135 amperes

being used for operation of the searchlight. Since these measurements using standard service instruments indicated a 40 percent electrical reserve during system operation, it was not considered necessary to install calibrated test instrumentation to isolate the apparent discrepancy between the 150 ampere calculated electrical load and the 135 ampere measured load. Approximately two hours of flight time were required for this test phase.

c. Basic Illumination Measurements: Flights were conducted to qualitively evaluate the amount of illumination delivered by the system. The degree of illumination produced is approximately equal to that of the Mk 6 flare; however, the area of illumination is considerably smaller. The light beam was placed outside the perimeters of defensive outposts and American advisors stated that the light was excellent and small details could be detected at ranges of 75 to 100 meters and that the illumination capability was usable at even greater ranges. Remarks of observers substantiated the theoretical calculations of illumination intensity, map inspections likewise substantiated the calculation of area coverage. Subsequent testing by ACTIV will provide further data on illumination capability of the device. It was found that the amount of backscattered light when operating in hazy conditions could be sufficient to make it impossible for the operator to see the ground. Under these conditions, observers in other helicopters reported that the ground illumination was not appreciably diminished. Employment of the system in haze would therefore require coaching the pilot and/or operator by radio to assist in properly positioning the light. Eight flight hours were required for this phase.

d. Operational Flight Tests: The illumination system was demonstrated to personnel of the US Army Support Command - Vietnam (USASC-V), Aviation Battalion Commanders and to Aviation Company personnel. All personnel expressed satisfaction with the amount of illumination produced. The system was used during several night training exercises and once during an actual night firing mission. Aviation company commanders stated that there was sufficient light to conduct a company-sized night airmobile operation. USASC-V personnel expressed a desire to purchase additional systems for subordinate units. RDFU-V has obtained a list of standard electrical components to be used in the construction of the system. This has been furnished to USASC-V for consideration. Twelve hours of flight time were required for this phase.

e. Equipment Modifications: The following modifications were made to improve the operation:

(1) One coat of heat resistant aluminum paint and two coats of heat resistant black paint were applied to the back of each sealed beam lamp to reduce the backlight from the system.

(2) A screw jack and handwheel system was installed to replace original wire and lever system of focusing.

(3) The aiming control handle and associated linkages were removed and replaced with a handle mounted directly to the lamp array.

f. Maintenance and Logistics: During the course of the evaluation no maintenance other than operator type was required on the system. There were no failures of electrical components; however, two hinges that attach the outer lamp brackets to the center lamp bracket were broken. This required fabrication of a new center ring assembly. SAMICO has been requested to increase the size of these hinges and/or use a different system of heat treating the casting. It was necessary to cover certain shiny surfaces of the aircraft with green cloth tape to reduce reflections back into the cabin area. These surfaces were places along the cargo floor edge and skid where the paint had worn off, exposing the underlying metal.

7. Findings: During the conduct of the evaluation it was found that:

a. The illumination system was aerodynamically compatible with the helicopter.

b. The illumination system was electrically compatible with the helicopter.

c. The time required to install and remove the system would permit normal daylight missions to be performed by the helicopter without the system installed.

d. The degree of illumination produced was approximately equal to that of the Mk 6 flare; however, a smaller area was illuminated.

e. The system provided adequate illumination for hamlet and outpost defense and for air support of night counterinsurgency operations.

f. The minor modifications made to the system improved the operational capability.

g. Only minor operator maintenance was required on the system.

8. Conclusions: As a result of the Phase I evaluation it is concluded that:

a. The heliborne illumination system provided satisfactory illumination for use in air-supported night counterinsurgency operations.

b. The system meets the requirement for devices organic to airmobile companies to supplement other illumination means.

9. <u>RECOMMENDATIONS</u>: It is recommended that:

a. ACTIV conduct Phase II of the evaluation to establish the operational suitability and the combat employment techniques for the system.

b. One additional system be procured using standard electrical components available through normal supply agencies.

c. The second system be used in addition to the present system during the ACTIV evaluation to determine any required design improvements.

d. That USASC-V be provided with detailed drawings and component lists so that expedited action may be taken on local procurement of additional illumination systems for operational use.

s/N. A. Rieke
t/N. A. RIEKE
CDR USN
Acting Chief

2 Incl
Appendix 1
Appendix 2

APPENDIX 1 TO ANNEX C

ELECTRICAL LOAD ANALYSIS

1. Referring to TM 55-1520-211-20, Part II, Organizational Maintenance Manual, Army Models UH-1B Helicopters, dated 29 July 1964, page 1-4, Figure 1-2, UH-1B Helicopter Power Loading Chart, for the electrical load analysis, we obtain the following data:

EQUIPMENT LOAD DURING SEARCHLIGHT OPERATIONS:

a.	Magnetic Brake	1.5 amperes
b.	Engine Oil Temperature	0.1
c.	Gyro compass	0.8
d.	Cockpit lights	0.3
e.	Instrument and edge lights	5.2
f.	Master caution panel	0.2
g.	Anti-collision light	3.0
h.	Relay, battery	0.6
i.	Relay, non-essential buss	0.6
j.	Relay, buss control	0.3
k.	Inverter, main	16.7
l.	Fuel boost pump	5.0
m.	Solenoid valve, governor bypass	1.0
n.	Actuator, govern RPM	0.9
o.	Radio compass (ADF)	2.8
p.	VOR receiver (VHF)	2.9
q.	FM homing adapter	1.0
r.	FM auxiliary receiver	0.1
s.	FM transceiver (receiver)*	4.9
t.	UHF transceiver (receive)*	17.0
	(additional for transmit)*	3.0
u.	VHF transmitter (standby)	1.5
v.	Relay, intercom	0.2
w.	Signal distribution panel	0.6
x.	Relay, auxiliary signal distribution panel	0.1
y.	IFF transponder	4.5
z.	IFF adapter	4.2
aa.	Radar altimeter	3.0
bb.	Fire detection	0.1
	TOTAL:	82.1

EQUIPMENT TURNED OFF DURING SEARCHLIGHT OPERATION

a.	Pitot tube heater	4.0 amperes
b.	Cabin heater	31.1
c.	Engine anti-icing	11.0
d.	Heated blanket outlets	20.0
e.	Red dome light	2.6
f.	Fuselage light	12.6
g.	Searchlight	17.0
h.	Windshield wiper	3.5
i.	Cargo hook release	10.2
j.	FM transceiver (transmitting)	1.4
	TOTAL:	113.4

*It is assumed that only one transmitter is in use at any given time, and that is taken to be the UHF transmitter since it is the transmitter which presents the greater electrical load.

2. The maximum electrical load for battery charging is 130 amperes. This is for the condition of a completely discharged battery. The battery is normally recharged within ten to fifteen minutes after starting and requires far less than the listed 130 amperes.

3. Each lamp is on an individual circuit with its own circuit breaker. It is thus possible to cut the electrical load of the illumination system by pulling the desired number of circuit breakers. Each lamp requires about 22 amperes. If it were desired to operate the system immediately after take-off in an aircraft that had a low battery, it might be necessary to operate with less than seven lamps for a short period. By observing the electrical load which is installed in all UH-1B aircraft, it is a simple matter to restrict the electrical load to the 300 ampere capacity of the generator on those rare occasions when the demand is greater than the supply.

APPENDIX 2 TO ANNEX C

ILLUMINATION CALCULATIONS

600 watt lamp, 6° half angle beam.

Theoretically, 55 lumen are produced per watt, or 33,000 lumens for a 600 watt lamp. A tungsten lamp is approximately 40% efficient in converting electrical power to light in the visible spectrum, the remainder of the power going into heat and non-visible radiation. Thus, each lamp will radiate about 13,200 lumens in the visible spectrum.

The foot-candle is a measure of illumination equal to the number of lumens per square foot. The area illuminated is about $A = h$ sine $6^{\circ})^2$ where h is the altitude above ground level of the helicopter. Hence, the average illumination obtained from one lamp will be 13,200/A foot-candles. The illumination for several lamps is an additive function of the individual illuminations. For the helicopter illumination system evaluated herein, the superposition of all seven beams would yield seven times the number of foot-candles illumination calculated for a single lamp. A graph presenting the illumination in foot-candles obtained from a single lamp at altitudes up to 6000 feet is presented in figure C-1.

The area illuminated by the array of lamps will depend on the positioning of the outer ring of lamps. The maximum area will result when the beams are just touching, which will provide about three times the diameter of the illuminated area for a single beam. The graph at figure C-2 presents the diameter of the illuminated area for a single beam versus the altitude of the lamp as well as the maximum diameter that may be illuminated with this system. The shaded area on this graph represents the attainable illuminated areas with this system.

The luminosity of the system may also be calculated since luminosity is simply lumens per steradian. It is found that the luminosity is about 384,000 beam candlepower per lamp. Thus, the array of seven lamps can be positioned to produce a 12° beam with about 2.7 million beam candlepower. This is a somewhat brighter source than the Mark 6 flare which has a nominal two million candle-power, but it must be noted that the flare is an omnidirectional emitter and will therefore illuminate a much larger area than the lighting system.

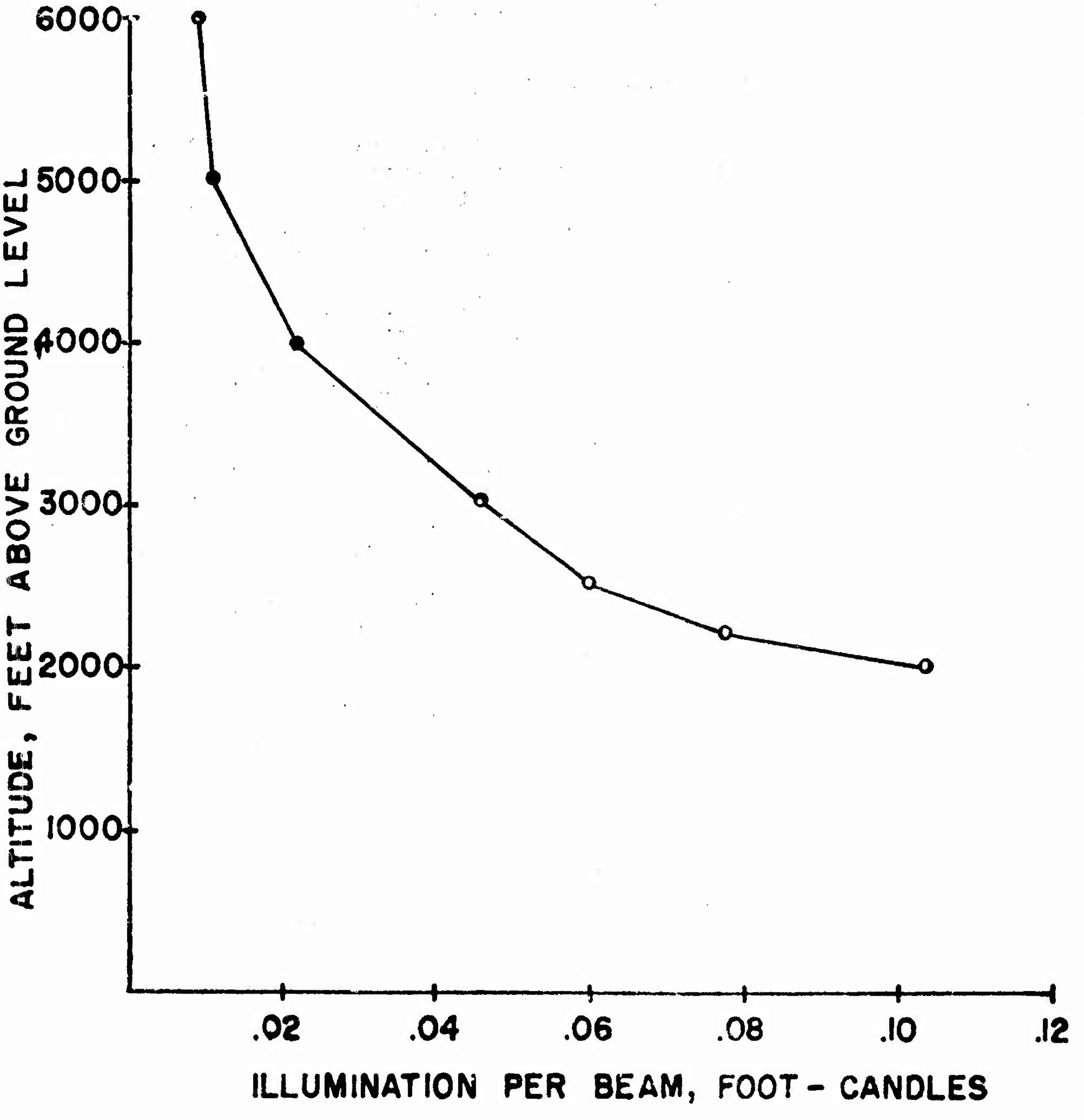

FIGURE C-1. Single lamp illumination in foot-candles.

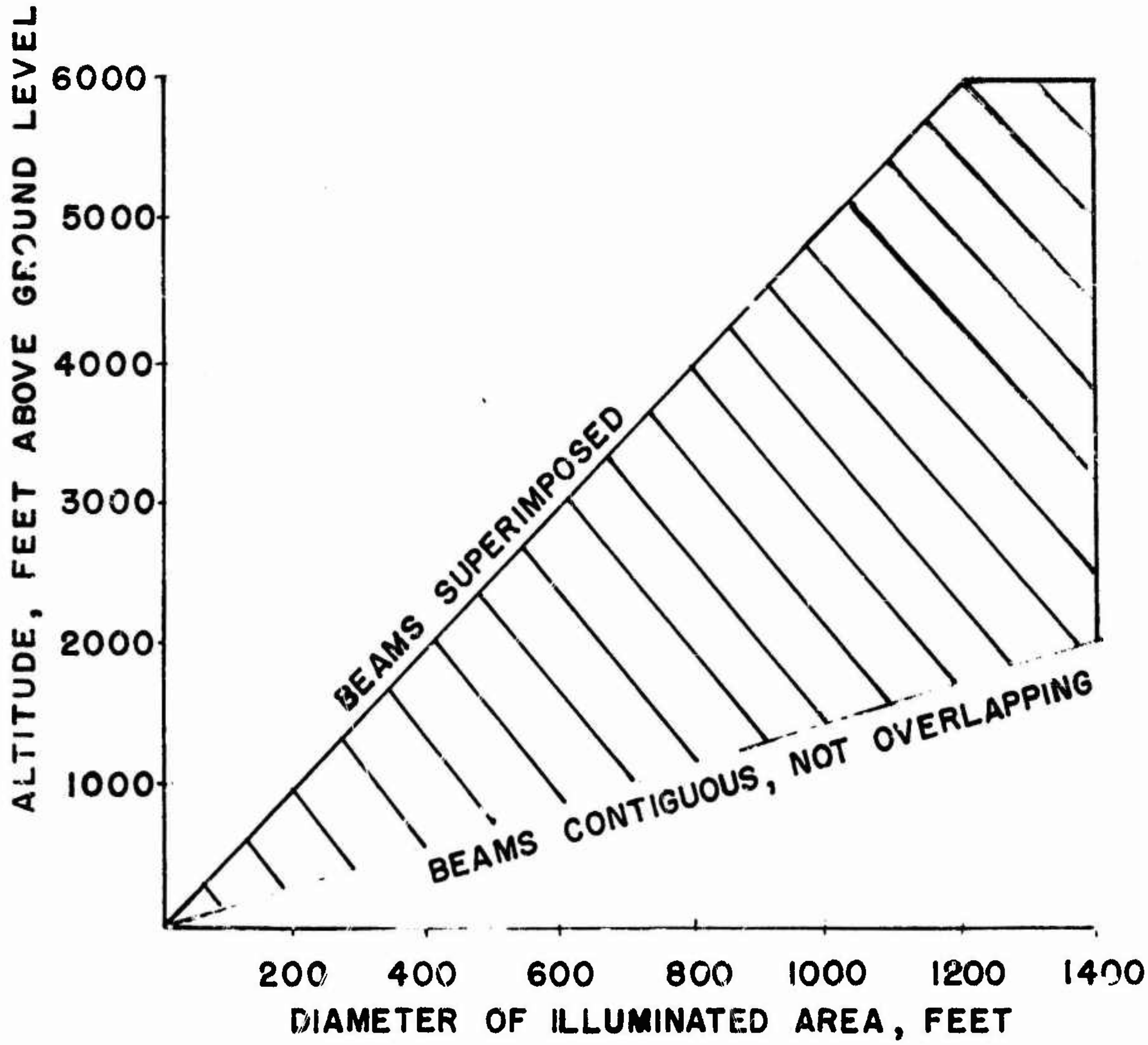

FIGURE C-2. Area of single beam illumination versus altitude.

ANNEX D

EQUIPMENT FAULTS

1. DEFICIENCIES

None

2. SHORTCOMINGS

None

3. CORRECTED DEFICIENCIES

Deficiency	Corrective Action	Remarks
a. Cracks and breaks developed in lamp brackets.	ACTIV had brackets fabricated locally from steel.	Second system incorporated the use of heat treated aluminum in lamp brackets.
b. Three switches had to be activated to turn on all seven lights.	New system incorporates single switch.	This reduced time required to activate/deactivate the system.
c. Original system was mounted in right door. This required the copilot to fly the aircraft while the pilot directed the searchlight.	New system is mounted in left door.	This allows the aircraft to be flown by the pilot.

ANNEX E

REFERENCES

1. ARPA letter, serial 630, subject: Project Proposal - Heliborne Illumination System Study, dated 9 November 1964.

2. JRATA letter, serial 4750, subject: Project Proposal - Heliborne Illumination System (JRATA Project Number 2L-506.0), dated 15 November 1964.

3. JRATA DF, subject: Project Establishment, dated 25 November 1964.

4. JRATA letter, serial 4801, subject: Project Proposal - Heliborne Illumination System (JRATA Project Number 2L-506.0), dated 25 November 1964.

5. CINCPAC message, DTG 130225Z January 1965, subject: Project Proposal - Heliborne Illumination System.

6. JRATA Menorandum, serial 5384, subject: Project Proposal - Operational Suitability and Combat Employment of a Heliborne Illumination System (2L-506.0), dated 1 April 1965.

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Security Classification

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Qualified requestors may obtain copies of this report from DDC.

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13. ABSTRACT The Heliborne Illumination System was designed by the Advanced Research Projects Agency, Research and Development Field Unit-Vietnam (ARPA RDFU-V) and fabricated in-country to supplement other methods of illumination in night combat operations. The HIS was flown under varying terrain, weather, and operational conditions on training and combat missions. Fifteen missions were observed by evaluators from the Army Concept Team in Vietnam (ACTIV). Additional data were gathered by interview and discussion with key personnel.

Generally, 2500 feet absolute was the most desirable altitude for the tactical employment of the HIS. An observer helicopter is normally required for surveillance of relatively small areas, troop formations, weapons emplacements, fortifications and similar-size targets. The observer helicopter follows the HIS just outside the light beam and at an altitude of 300 to 500 feet. A fire team of 3 armed helicopters trails 500 feet to the rear and at an altitude of 1500 feet absolute to provide protection for the serachlight and observer helicopter and also firepower for target engagement.

The HIS evaluated in this project is a satisfactory interim solution for the increased night illumination requirement. Although a step in the proper direction, it is not the optimum solution and research should be continued to develop a standard aerial illumination system for combat operational use.

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	ROLE	WT	ROLE	WT	ROLE	WT
Illumination system, heliborne						
Counterinsurgency Operations, Vietnam						

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GENESIS of INFRARED DECOY FLARES

The early years from 1950 into the 1970s

Report Documentation Page

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GENESIS of INFRARED DECOY FLARES

The early years from 1950 into the 1970s

1st Edition

Bernard E. Douda, PhD
Naval Surface Warfare Center, Crane Division
Crane, Indiana USA

January 26, 2009

Cover image: Lockheed C-130 Hercules aircraft jettisoning decoy flares.

TABLE OF CONTENTS

PREFACE

The idea to preserve information about the early development of target, augmentation and mainly infrared flares came about 15 years ago. I thought that collection of the information is needed because early records are sparse, scattered, and most are inaccessible to all but those in government. Most of the records were classified and even though the classification later was removed, the documents are not in the unlimited distribution category. As a government employee I could still access many of the records and hopefully extract pertinent information. There did not seem to be any urgency to complete the task. However as “retirement” appeared on the horizon, it became increasingly more urgent for me to compile the notes I had collected throughout my years of service. And now, I have reached the time that the task must be completed or it never will come to fruition.

My objective is to compile information relevant to the development of flares, mainly infrared decoy flares, during the 1950s through most of the 1970s. I wanted to make a conscious effort to preserve a small part of our national history. In later years, decoy flare data have been archived better and are easier to locate. However, most remain inaccessible to the public due to sensitivity limitations. And from a practical standpoint, the task to compile data that includes all developments into the 2000 era would be more than my limited time available would allow.

I’m certain I did not locate and capture all information relevant to decoy flares in the early years. Some of the information presented appears incomplete and does not flow continuously. Nevertheless, I tried to provide a synopsis of an event in an effort to give the reader a sense of the magnitude of the effort, the wide range of technology that was brought to bear, the thoroughness with which the researchers explored the problem, the urgency of the effort to provide a solution to a critical threat, the lack of sophisticated technology that would be needed to complete the development or flare evaluation effectively, and the huge number of flare developmental efforts ongoing simultaneously. With respect to data details about each flare, I provided an abbreviated description of the device when available and the application for which the item was designed. I recorded the item’s existence even though information about it was meager.

<u>Flare Terminology</u>: The “jargon” used by flare developers and report writers especially in the early years tended to use the flare descriptive terms “target” flare and “augmentation” flare interchangeably. Similarly, during description of development, testing, or other flare event, the “Mod” of a flare was not always indicated, leading to some ambiguity. Exact terminology doesn’t take hold until the device is officially assigned nomenclature usually when it transfers to production and service use.

Munition and Equipment Nomenclature: My objective includes the desire to identify equipment, aircraft, drones, dispensers, and related hardware by their assigned nomenclature. To do so helps to show how and what additional devices are required to be operative during deployment or testing of a flare.

Units of Measure: Due to the age of the material, most units of measure are presented in English units. Occasionally, the units are also provided in Systems International (SI) units.

A Note on Names: Included in my objective to compile data is my desire to record names of the researchers and the organizations with which they are associated. I believe it important to give credit to the individuals involved in the work. As one goes through the years of developmental effort, it becomes clear that certain individuals and organizations were heavily and continuously involved more so than others.

Upon first use of a name in the narrative, I provided the full name with title when known and employer identification complete with location. Upon further occurrence in the text, the individual is identified by “Sir” name only and title when known. The default title is “Mr.”

Dates: Except where stated exactly, the dates given correspond to the date of the document such as a technical report from which the information was extracted. In reality, the actual dates during which the work took place is most likely a year or even two or three earlier than the report date. Similarly, the actual date of an invention cited in a patent is a year or more earlier that the filing-date of the patent application.

Acknowledgements:

I wish to acknowledge and thank the many people that helped me in this endeavor in so many different ways. Mr. Burl Phillips and the PMA-272 Program Office for Expendables provided support. I also owe a debt of gratitude to my management superiors at the NSWC Crane Division, who supported me all these many years. The infrared flare development team at NSWC Crane Division, and especially Mr. Steven Norris, helped to provide information about decoys. Mr. Rob Parker and Mr. Tommy Sanders of NSWC Crane Division located and provided considerable data regarding obsolete flares. Mr. Davis Shryer, a former employee of the 3M Corporation, provided considerable information about the origin of Teflon®, Viton®, Kel-F® and related materials. Ms. Caroline Amey of Hill Air Force Base provided clarification about the flare contents within MJU-7/B flares and MJU-7A/B flares. Mr. Charles Denham, NSWC Dahlgren Division, provided information about the HERO program and the USS Kearsarge CV-33 incident. Mr. Richard J. Sorenson and Mr. Richard D. Hunziker provided information about the origin of the AN/ALE-40 dispenser. The librarians and their staff at NWC China Lake were most helpful in providing copies of old NOTS patent literature. Dr. Anthony Cardell OBE, a long-time pyrotechnic and fireworks notable, helped me compile the information about the history of UK pyrotechnics at RARDE Langhurst UK and at RARDE Fort Halstead UK. Mrs. Tracy Murphy helped to obtain copies of over 350 documents from which information was extracted to make this compilation. To all these persons, I say thank you very much.

ACRONYMS and ABBREVIATIONS

3M	Minnesota Mining and Manufacturing
ACE	Advanced Cost Effective project
ADTC	Air Development Test Center, Eglin Air Force Base, Florida
AEDC	Arnold Engineering Development Center, Arnold Air Force Station, Tennessee
Aerojet-General	Aerojet-General Corp., Azusa, California.
AFAL	Air Force Avionics Laboratory at WPAFB
AFATL	Air Force Armament Test Laboratory, Eglin Air Force Base Florida
AFB	Air Force Base
AFCRL	Air Force Cambridge Research Laboratory, Laurence G. Hanscom Field, Bedford, Massachusetts
AFIT	Air Force Institute of Technology, WPAFB
AFSC	Air Force Systems Command
AGC	Aerojet-General Corporation
AIDES	Airborne Infrared Decoy Evaluation System
aka	also known as
AMC	U. S. Army Missile Command, Redstone Arsenal, Alabama
APGC	Air Proving Ground Center, Eglin Air Force Base, Florida
ARC	Atlantic Research Corporation, Saugus, California
ARC-Virginia	Atlantic Research Corporation, a division of Susquehanna Corporation, Alexandria, Virginia
ARD	Armament Research Department (UK)
ARF	Armour Research Foundation of IIT, Chicago, Illinois

ARPA	Advanced Research Projects Agency
ASD	Aeronautical Systems Division at WPAFB
ASP	Atmospheric Sounding Projectile
ASW	Anti-Submarine Warfare
ATIMS	Airborne Turret Infrared Measurement System
BATS	Ballistic Aerial Target System
BOF	Balls of Fire
BuAir	Navy Bureau of Aeronautics, Navy Headquarters, Washington, DC
BuOrd	Navy Bureau of Ordnance, Navy Headquarters, Washington DC
BuWeps	Bureau of Naval Weapons, Washington, DC
C2F4	tetrafluoro monomer
C3F6	perfluoropropene also known as hexafluoropropylene
CalTech	California Institute of Technology
CDC	Cooper Development Corporation, Monrovia, California
CTFE	chlorotrifluoroethylene, C_2F_3Cl
CTFE wax	Kel-F® #40
CTPB	carboxy-terminated polybutadiene
DEAC	diethylaluminum chloride
DEAH	diethylaluminum hydride
DEM	diethylmagnesium
DERA	Defence Evaluation Research Agency (UK)
DIBAH	diisobutylaluminum hydride

DRA	Defence Research Agency (UK)
DSTL	Defence Science and Technology Laboratory (UK)
DTI	DynaTech Inc., Tempe, Arizona
DuPont	E. I. du Pont de Nemours, Inc.
ECF	electrofluorination process
ECOM	Electronics Command, Fort Monmouth, New Jersey
EED	Electro-Explosive Device
EMCON	Emissions Control
EOD	Experimental Operations Department or Explosive Ordnance Disposal
ESD	electrostatic discharge
EX	experimental as in EX 46 Mod 0 flare
FA	Frankfort Arsenal
FAC	Forward Air Controller aircraft
FFAR	Forward Firing Aircraft Rocket flare
FFAR	Folding-Fin Aircraft Rocket
Flare Northern Division of ARC	Flare-Northern Division, Atlantic Research Corporation, Saugus, California
FM	frequency modulation
FOI	Federal Ordnance Incorporated, Mechanicsville, Maryland
FS-1265™ fluid	methyltrifluoropropylsiloxane
GD	General Dynamics Corp, San Diego, California
g/cc	grams per cubic centimeter
gran	granulation

HARP	High Altitude Research Program
HASC	High Altitude Simulation Chamber
HERO	Hazards of Electromagnetic Radiation to Ordnance
HISIP	High Speed Instrumentation Pod
HPAG	High Performance Air To Ground Rocket.
HVAR	High Velocity Aircraft Rocket
IIT	Illinois Institute of Technology, Chicago, Illinois
IITRI	Illinois Institute of Technology Research Institute
IPA	Isopropenylacetylene
IR	infrared
IRAD	Internal Research and Development Program
IRCM	Infrared Countermeasure
IRIS	Infrared Information Symposia
JHU	Johns Hopkins University
K	Kelvin temperature
Kellogg	M. W. Kellogg Company
KIAS	knots indicated air speed
MEK	methyl ethyl ketone
Mfg.	Manufacturer
MIT	Lincoln Laboratory, Massachusetts Institute of Technology
Mk Mod	Pronounced Mark and Mod as in Mk 46 Mod 1 decoy flare
MSL	mean sea level
MTV	Magnesium/Teflon®/Viton® A

NAD Crane	Naval Ammunition Depot, Crane, Indiana
NAVAIR	Naval Air Headquarters, Washington, DC
NBS	National Bureau of Standards
NMC	Naval Missile Center, Point Mugu, California
NOL White Oak	Naval Ordnance Laboratory, White Oak, Silver Springs, Maryland
NOLC	Naval Ordnance Laboratory, Corona, California
NOS Indian Head	Naval Ordnance Station, Indian Head, Maryland
NOTS	Naval Ordnance Test Station, Inyokern, China Lake, California
NPF Indian Head	Naval Powder Factory, Indian Head, Maryland
NPG Dahlgren	Naval Proving Ground, Dahlgren, Virginia
NPP Indian Head	Navy Propellant Plant, Indian Head, Maryland
NRL	Naval Research Laboratory, Washington, DC
NWC China Lake	Naval Weapons Center, China Lake, California
NWSC Crane	Naval Weapons Support Center, Crane, Indiana
ONR	Office of Naval Research, Washington, DC
ORI	Ordnance Research Incorporated, Fort Walton Beach, Florida
OSDR	Office of Scientific Research and Development
PA	Picatinny Arsenal, Dover New Jersey
PBX	plastic bonded explosive
PENVAL	Penetration Evaluation Program
PETN	pentaerythritol tetranitrate
PFHM	polyfluoroheptylmethacrylate

PL	Pilot Lot
PMTC Point Mugu	Pacific Missile Test Center, Point Mugu, California
PMVT	polymethylvinyltetrazole
PPE	Prototype Production for Evaluation
PTFE	polytetrafluoroethylene
QRC	Quick Response Capability
Rad	A rad is a unit of radiation quantity of absorbed dose. One rad is equal to energy absorption of 0.01 J/kg of any material
RAE Farnborough	Royal Aircraft Establishment, Farnborough, Hants, England
RARDE Fort Halstead	Royal Armament Research and Development Establishment, Sevenoaks, Kent, UK
RARDE Langhurst	Royal Armament Research and Development Establishment, Langhurst, Horsham, West Sussex, UK
RBOC	Rapid Blooming Offboard Chaff
RF	radio frequency
RMC200	Reade Metals Corporation granulation grade 200 magnesium powder
RTD Eglin	Research and Technology Division, Eglin Air Force Base, Florida.
S&A	safe and arming device
SCAR	2.25-inch Sub-Caliber Aircraft Rocket
SI	Systems International
SOID	Ships Ordnance Infrared Decoy
SR	Superintendent for Research
SRI	Stanford Research Institute, Menlo Park, California
TEA	triethylaluminum

Thermoplastic 125	styrene-butadiene copolymer
TME	trimethylethylene
TNPA	tri-n-propylaluminum
UK	United Kingdom
UMC	Universal Match Corporation, Saint Louis, Missouri
USA	United States of America
USAF	United States Air Force
USF of ARC	U. S. Flare Division of Atlantic Research Corporation
USFC	US Flare Corporation, Pacoima, California
USN	United States Navy
UTC	United Technology Center, Sunnyvale, California
µm	micrometer
VF2	vinylidene fluoride
Vistanex®	a polypropylene polymer
VX-4 Point Mugu	Air Test and Evaluation Squadron Four, Point Mugu, California
W/sr	watts per steradian
WADC	Wright Air Development Center, WPAFB
WMU	Weather Modification Units
WPAFB	Wright Patterson Air Force Base, Dayton, Ohio
WW II	World War II

INTRODUCTION

The evolution of decoy flares did not follow a direct or pre-planned path. Instead, the development was influenced by many factors and requirements existing at the time. One of the most important of these is that the Naval Ordnance Test Station (NOTS), Inyokern China Lake, California had an assigned mission to develop rockets and missiles. This mission became the basis for the requirement that drove flare developments. Fortunately there were a number of ongoing projects at China Lake that supplied expertise and the technological foundation. These were important for the Sidewinder missile and infrared decoy flare developments. Discussions of these topics follow.

ORIGIN of the SIDEWINDER MISSILE SEEKER

The saga of the development of the Sidewinder missile revolves about one brilliant scientist at NOTS with a vision. Dr. William Burdette McLean, father of the Sidewinder, began to conceive of the Sidewinder missile in the 1940s. Dr. McLean proposed the air-to-air target seeker to the Washington DC hierarchy in November 1947 and demonstrated it in February 1948. To fully understand details of the improbable development of the Sidewinder heat-seeking missile and the genius of Dr. McLean, one needs to read the book, *Sidewinder, Creative Missile Development at China Lake*.[1]

The ingenious management talent of Dr. McLean, in the environment of NOTS China Lake during the 1940s and 1950s, is one of his attributes that made the Sidewinder missile a success. He organized teams of individuals whom he selected. He either personally interviewed and hired prominent scientists for his teams or had them assigned from other segments of NOTS China Lake but only after a personal interview and selection process. Not only did the individuals need to have outstanding technical talent and reputations but they also had to have a driven work ethic and a can-do attitude. Work after hours, at the swimming pool, during an evening dinner at his home and in the middle of the night was the norm. To cope with the urgency, he often assigned the same goal to multiple competing teams to increase the probability of an early solution to the problem at hand.

The team of Dr. Lucien M. Biberman of the Office of Associate Director for Research and Development of NOTS and Mr. Edwin G. Swann and Mr. John J. Miyata of the Research Department Optics Branch of NOTS was created by Dr. McLean to solve the detector and tracking difficulties when operating in a sky background. Mr. Swann and Mr. Miyata were on assignment from the Optics Branch through the cooperation of the Branch Head Mr. Walter Wallin. The organization of

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[1] Westrum, Ron Sidewinder. Creative Missile Development at China Lake. Naval Institute Press, 291 Wood Road, Annapolis, Maryland, 1999: ISBN 1-55750-951-4.

such a “Consultants Group” under the guidance of Mr. R. S. Estey is one example of Dr. McLean’s management skills. Their task assigned prior to 1951 was to design a photocell and electronic components for a heat homing system. The feasibility study was called Fox Sugar 567 and had started earlier as local project 612.

The report of the Consultants Group describes the design of the photocell and electronic details of an infrared homing device for a rocket. They discuss variables associated with the amplifier bandwidth and time constants of lead sulfide cells, a limiting design factor. They show how a multi-slit scanner and a special slit pattern can be used to strongly suppress the sky background. They describe an amplifier that uses the signal to control currents in four precessing coils or control circuits that represent the direction and radial distance of the target image from a reference on the missile axis.

The entire program was under the direction of Dr. McLean. Reviewers of the work of the Consultants Group were Dr. McLean, Mr. F. T. Rogers, and Mr. Estey. The Associate director for Research and Development was Mr. F. W. Brown. Mr. L. T. E. Thompson was the Technical Director of NOTS at this time.[2]

Dr. Marshall D. Earle of the Aerospace Corporation in Los Angeles California, in 1978 while describing the principles involved in infrared tracking devices wrote, “The phenomenal success of this type of missile is from two achievements: the development of short-time constant high sensitivity photoconductive detectors and development of means by which a small target which occupies only a small part of the field of view can be distinguished from its background.” This was the seminal achievement of Dr. Biberman’s team. In *Spectral Reflections*[3] it states Dr. Biberman invented the missile guidance concept used in several generations of Sidewinder missiles: conceived missile warning technology now used by Special Forces and Marine aircraft; and played the key role in designs of AIM-9 Sidewinder missiles.

The first flight tests of Sidewinder (EX-0) missiles took place starting 14 May 1952. The missiles were fired at an F6F-5K drone aircraft from an A4-D aircraft. The Sidewinder missile was introduced into the U. S. Navy Fleet for the first time in 1956.

[2] The title of the above researchers and others in this document most likely is “Dr.” instead of “Mr.” which was assigned by default when unknown.
[3] Spectral Reflections. Newsletter published by Infrared Information and Analysis Center (IRIA), Michigan University, Ann Arbor, Michigan. January 2000.

ENABLING TECHNOLOGIES

To develop a heat-seeking missile, a number of enabling technologies needed to be developed or improved upon. For example, seeker technology and algorithms were needed to distinguish the target from the background. A photoconductive cell detector was needed. Computational methods and hardware were inadequate. Radiometric and spectral instruments were either non-existent or in their embryonic state. Measurement capability was needed in the infrared, ultraviolet and in the visible for utilization on the ground and in the air. No airborne radiometric and spectral instrumentation existed. Equipment to test and evaluate flares to simulate functioning at altitude also did not exist and although research in fluorocarbon chemistry was ongoing at NOTS, it needed to be adapted to the current needs. To complement their growing ability to make measurements in the infrared, ultraviolet and visible spectral regions, in 1954 NOTS assembled an electronic countermeasures test facility consisting of off-range facilities and equipment, range instrumentation, and a mobile caravan containing jammers, intercept equipment and transmitter-receivers. All these technological areas needed to be advanced sufficiently to enable their adoption into a missile seeker design. As technologies advanced there was need to test the seeker concepts first against drones and finally in live-fires. This required development of augmentation flares, target flares and ultimately infrared decoy flares in order to be able to record the event with some accuracy.

Lead Sulfide and Lead Selenide Photoconductive Cell Detectors

Photo-conductor technology was critical to the development of the Sidewinder missile by NOTS. The lead sulfide (PbS) photoconductive cell was chosen to be the detector of visible energy radiated from rockets and missiles and later of near-infrared radiation from the targets, aircraft, missiles and rockets. Without this device, the Sidewinder missile would not be able to engage its target. The lead sulfide detector also was used to measure the radiative output in the visible and near-infrared region of tracking flares, augmentation flares, and infrared decoy flares. In the early 1940s, the detector had not been sufficiently developed to allow direct application into a device. Additional development was needed, some of which took place at NOTS.

One can review the background of the evolution of the lead sulfide photoconductive cell. On 30 September 1901, Mr. Jagadis C. Bose of Calcutta India filed for a patent for a Detector of Electrical Disturbances later to become U. S. Patent 755,840 in 1904. Mr. Bose had discovered the photosensitive property of lead sulfide (galena). In 1917, Mr. T. W. Case reported the change of resistance of certain substances to light. Later, lead sulfide detectors were developed in Germany by Mr. Gudden in the 1930s and were used in some systems in World War II (WW II). In 1944, Mr. R. J. Cashman developed the first practical lead sulfide detector in the U. S. In 1951, Dr. Biberman of the Office of Associate Director for Research and Development and

Mr. Swann and Mr. Miyata of the Research Department Optics Branch of NOTS, reported on the Design of Photocell and Electronic Components for a Heat Homing System. The technology developed and reported in that study provided one of the critical technologies needed to build the Sidewinder missile.

In 1957, the Navy Bureau of Aeronautics (BuAir) in Navy Headquarters Washington, asked China Lake to evaluate lead selenide nitrogen-cooled photoconductive cells. Mr. Victor A. Ereaux and Mr. Eugene K. Lawson of the Aviation Ordnance Department at NOTS conducted the study of cells made by Santa Barbara Research Center, Goleta California. They made measurements of spectral response and blackbody radiation. Detector research at China Lake, including lead sulfide studies, continued into the late 1960s.

Thermodynamic Computations and the Analog Computer

About the same time, 1950, Dr. William S. McEwan of the NOTS Research Department reported on a system for the computation of gaseous products of combustion to determine their equilibrium composition and thermodynamic properties of the combustion gases.

In 1951, Dr. McEwan and Dr. Sol Skolnik developed an analog computer that electrically simulated the conditions of temperature, pressure and composition of rocket and missile combustion products. With these improved computational capabilities, they were able to make better and quicker estimates of rocket and missile performance.

Radiometric and Spectral Measurement Instrumentation

The ability to perform radiometric and spectral measurements also needed to be developed to measure the radiative and spectral output of rocket and missile plumes, exhaust plumes of aircraft and the output of flares of all types. During development of tracking flares, China Lake employees needed the ability to measure characteristics of energy radiated from the burning devices in the visible region as well as in the infrared region of the spectrum. Fortunately, the Technology Department had an ongoing effort to continually improve the equipment and techniques while other developments were in progress. In addition, other laboratories also were building improved measurement instrumentation. Collectively, these efforts provided improved means to make measurements thereby enabling flare developers to better assess their technological advances.

Even as late as 1976, Picatinny Arsenal provided a list of instrumentation needed for pyrotechnic research and technology. These are: (1) stable photocells and stable amplifiers, (2) high speed spectrograph, (3) high sensitivity infrared photocells, (4) rugged, portable and simple to operate color meters for flares, (5) a light integrator for flares, and (6) rapid computers and integrators for flash evaluation. This deficiency list is an example of some of the technological voids at

that time. It is surprising to learn that high quality capable instruments that we take for granted today were unavailable to the researchers of that era.

The Experimental Operations Department (EOD) of NOTS developed and made measurements of the Forward Firing Aircraft Rocket (FFAR) flare, reported in 1946. They also experimented with measurement of the illuminating characteristics of 3-inch and 4-inch projectiles and aircraft flares. Trajectory measurement of the Target Rocket Mk 3 was reported by the Science Department in July 1946. Between June 1956 and January 1957, Mr. David Gilbert and Mr. Frank B. St.George measured flare radiant output using a locally developed NOTS Model 34A radiometer. This radiometer used a lead sulfide detector capable in the 0.5μm to 3.0μm bandpass region.

About 1954, Dr. Earle, Johns Hopkins University (JHU) Carlyle Barton Laboratory (Radiation Laboratory) constructed a Rapid Scan Spectrometer that might have been the forerunner to the Perkin Elmer Model 108 spectrometer that became ubiquitous in pyrotechnics laboratories. His spectrometer could scan at 1 per second through the visible up to 1.2μm and from 1μm to 4μm in the infrared.

In mid-1956, under contract to the Wright Air Development Center (WADC), Wright Patterson Air Force Base, Dayton Ohio (WPAFB), the Eastman Kodak Company, Rochester New York, developed ground and airborne instruments for measuring the infrared radiative output of jet engines, rockets, and flares. They installed a Perkin Elmer Rapid Scan monochrometer into an F-94 pylon tank. The monochrometer was wrapped in a heating blanket. Its line of sight was through a sapphire window.

In 1955 -1956, the Navy Bureau of Ordnance (BuOrd) assigned a task to China Lake to develop a photometric system for measuring intensity and duration of pyrotechnic signals. Initially the instrument was intended to measure the output of the Mk 37 Mod 0 flash signal for the Sparrow III guided missile, the Mk 36 Mod 0 flash signal for the Sparrow II missile, and the Mk 1 Mod 0 flash signal and Mk 2 Mod 0 flash signal for the Sidewinder exercise head. The light intensities from these emitters ranged between 100,000 candela and 200,000,000 candela with durations of less than 5 milliseconds to several seconds. The flash signals were used during missile tests to indicate fuze action. The NOTS Model 751A flash signal indicates fuze actuation for the Sparrow I missile.

Efforts continued to improve measurement accuracy. During 1958, Mr. H. I. Sumnicht of the Aviation Ordnance Department of NOTS observed that when using radiation detectors, there is a need to quantitatively determine the degree that a source will affect a response in the radiation detector whose response curve shows spectral variation. To remedy that deficiency, he developed a method whereby the unknown radiative source is evaluated by comparing it with a source of known power distribution.

Under the auspices of the Metrology Department of the Bureau of Naval Weapons (BuWeps) at Pomona California in 1958, eleven U. S. Navy calibration labs were established because of overload at the National Bureau of Standards (NBS). Their tasks included the calibration of a blackbody and an optical comparator system in support of decoy flare tests and other Navy programs. The primary blackbody followed the design developed about 1950 by an NBS standards group at the Naval Ordnance Laboratory, Corona California (NOLC).

During a 1960 Conference, Mr. Philip J. Smith of the Naval Ammunition Depot (NAD), Crane Indiana presented problems encountered in making luminous intensity and infrared measurements. The test tunnel configuration, positioning of the test unit, smoke obscuration, smoke exhaust, and measurement instrumentation were discussed. Mr. Armin T. Wiebke of NOTS described the instrumentation that had been developed at China Lake. That instrumentation included a vacuum phototube for measurement in the visible region and lead sulfide cells mounted behind interference filters for infrared measurement in the 2μm to 3μm bandpass region.

Efforts to improve measurement of the output of infrared decoys continued. About 1960, Mr. Jason Sarnow of the Navigation and Guidance Laboratory, Wright Air Development Center, WPAFB reported on a convenient method for correcting errors in spectral analyses of high energy sources resulting from attenuation due to atmospheric and filter factors in the region of 0.3μm to 6.3μm bandpass region in 0.2μm increments. In 1961, Mr. Ephraim Regelson, Mr. D. K. Burge, and Mr. M. Wayne Claunch of China Lake reported development of a color wheel radiometer using eight filters covering the range from 2μm to 6μm bandpass region. The radiometer was used to acquire spectral information about the Mk 28 Mod 0 target flare (NOTS Model 711A flare) and the NOTS Model 712A target augmentation flare.

Also about 1960, Mr. E. J. Cleary and Mr. J. R. Carter of China Lake developed an airborne color wheel spectral-radiometer to measure radiant energy in the 2μm to 5μm bandpass region. It is packaged in a 5-inch diameter tube by 92 inches long and can be mounted on any aircraft equipped to carry Sidewinder missiles. The instrument is designed to function at altitudes up to 50,000 feet and at speeds of Mach 1.6. The data are recorded on 16-mm film. They collected radiative data from the exhaust of the B52-H turbofan aircraft and compared measurements of ground-burning flares to airborne-burning flares.

A second type of NOTS airborne radiometer was developed about 1961. It was a fixed-band device utilizing a liquid nitrogen cooled lead selenide detector and an optical interference filter with a 2.5μm to 5.0μm bandpass. This equipment was mounted under the wing of an F-3D aircraft for measuring the radiative output of airborne flares.

In 1962, Baird Atomic, Incorporated, Cambridge Massachusetts reported the development of a turret mounted scanning spectrometer capable of making spectral measurements using cooled lead selenide detectors of 0.2μm resolution in the 1.5μm to 4.7μm bandpass region at altitudes above 65,000 feet.

Mr. Ralph Zirkind of the Advanced Research Projects Agency (ARPA), Lt Col Lavern A. Yarbrough USAF, Dr. Paul J. Cvrebo of AFSC and Mr. Lawrence W. Nichols of NOTS presented a paper entitled Techniques for Measurements of Infrared Radiation Characteristics of Airborne Targets at a NATO May 1963 meeting in Paris France of a group of experts on far infrared. The NATO community observed apparent discrepancies in the data. As a result, the group undertook the task to evaluate about 24 instruments in service use and some developmental items.

As part of infrared spectroscopy research at China Lake in the mid-1960s, the investigators continued to evaluate circular variable filters. The quest for improved instruments for measurement of infrared radiation from missiles, aircraft and flares was continuing with vigor. During 1964 and 1965 meetings of the Infrared Information Symposia (IRIS) many papers on detector materials and transmission glasses were presented. Also included were presentations about a high performance interferometer for airborne applications, an airborne infrared spectrometer system, an infrared band ratio technique to determine temperature, and a method to obtain the concentration ratio of carbon dioxide to water (CO_2/H_2O) in rocket exhaust plumes.

In May 1963, a Specialty Group of IRIS concluded that the physical standardization of radiation sources was one of the most important areas to cover on a continuing basis. As a result, a survey was made of radiation-source standardization. Five laboratories in the USA are listed as having formal radiation-source standardization programs: (1) National Bureau of Standards, Washington, D.C., (2) U. S. Air Force Calibration Group, Newark, Ohio, (3) The Eppley Laboratory, Inc., Newport, Rhode Island, (4) Bureau of Naval Weapons Representative, Pomona, California, and (5) Hughes Aircraft company, Tucson, Arizona. The National Physical Laboratory at Teddington, England was added to this review. Three types of radiation standards were considered: blackbody radiation source standards, detector standards, and incandescent source standards. Comments were made on the problems of temperature, cavity theory, polar angle, NBS traceability, and calibration procedures. They identified the need for a blackbody calibration service. The team noted that accuracies for radiation-source standardization measurements are 0.2% to 5% or even larger percentages depending on the type of measurement.

In May 1963, Mr. Regelson of China Lake filed for a patent for an infrared calibration lamp. His objective was to provide an infrared calibration source that was suitable for field use where environmental conditions make it difficult to use laboratory type standards. Another objective was to provide an infrared source

small enough to serve as an internal source for radiometric equipment that offered a combination of accuracy, small size, ruggedness, and low cost.

In a 1968 report, Mr. G. S. Amick of Airtronics, Inc in Washington DC conducted a deviation analysis of infrared measurements in an effort to develop a standard way of doing infrared countermeasure measurement and tests.

ALA-17 flares and ALA-34 flares were tested at Eglin Air Force Base about 1970 with an Air Force developed Airborne Infrared Decoy Evaluation System (AIDES), a 2-color radiometer operating in the 3.8μm to 4.9μm bandpass region with a lead selenide detector and in the 1.8μm to 2.7μm bandpass region with a lead sulfide detector. The AIDES pod is mounted in or on a MacDonnell Aircraft Instrumentation Pod, which is suspended from an F-4C aircraft. The AIDES pod carries an AIM-9B Sidewinder and an AIM-4E Falcon. Dr. David J. Edwards of the Air Development Test Center (ADTC) at Eglin Air Force Base managed this effort.

High Altitude Simulation Chamber

A High Altitude Simulation Chamber (HASC) was built at NOTS in support of their High Altitude Research Program (HARP). To fill the need for evaluating performance of flares at high altitude, Dr. George S. Handler of China Lake took the lead to install a rapid scanning infrared spectrograph in the HARP high altitude chamber about 1963. A photo multiplier tube is used to record visible and near infrared energy, a lead sulfide cell is used for the 0.5μm to 3.0μm near infrared and a lead selenide cell is used for the 4.5μm to 6.0μm bandpass region. Later, during 1970, the HASC was modified to enable experiments at 0.8 Mach and 40,000 feet altitude. A choke flow diffuser flow system was added to make possible the determination of flare characteristics at altitude and various subsonic velocities.

How Teflon®, Viton®, and Kel-F® Came into Being

In 1996, Mr. Davis Shryer[4], a long-time 3M employee, related the story from personal recollection of how tetrafluoroethylene was discovered and also the background of the evolution of Kel-F® wax, Kel-F® elastomers, Viton® A and other fluorocarbon materials. He noted that its accuracy may be slightly tainted by time, but that the essentials are correct.

He said, as far as the USA is concerned, the story has to begin with E. I. Dupont, which invented and produced fluorocarbon refrigerant gases (Brand named "Freon") in the first decades of the 20th century. An E. I. Dupont researcher named Dr. Roy Plunkett was experimenting in the 1930s with a tetrafluoro monomer (C2F4), derived from by-products of the "Freon" process. One day in his laboratory Dr. Plunkett attached a small cylinder of this gas to an apparatus intending to

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[4] Personal communication with Mr. Davis M. Shryer, retired from the 3M Company, and later a consultant to the Mach I Corporation. 1996.

introduce the gas into a reaction vessel. When he opened the cylinder valve, no gas emerged. The incident became known as "Plunkett's Perplexity", because upon removing and weighing the C2F4 cylinder, he found that its weight had not changed. Where then were the contents? To find out what had happened to the gas, he cut open the cylinder and found a white waxy solid. This, in 1938, was the first discovery of polytetrafluoroethylene (PTFE) that was later, branded "Teflon®". Subsequently, E. I. Dupont produced PTFE for seals, gaskets, etc for use in the chemical processes of the Manhattan Project, where highly corrosive intermediates such as sulfur hexafluoride were processed.

The M. W. Kellogg Company (Kellogg) produced chlorotrifluoroethylene (CTFE, C_2F_3Cl) plastics and lubricants for the Manhattan project and at the end of WW II elected to manufacture them commercially under the brand name “Kel-F®”. Dr. Miller at Cornell University had developed CTFE under a U. S. government contract. Kellogg also produced fluoroelastomers that were copolymers of CTFE and vinylidene fluoride (VF2), an available monomer. It turned out that these elastomers had a lower degree of oil resistance than 3M’s fluoroacrylates and were extremely difficult to process into finished rubber goods.

During their research on the CTFE/VF2 polymer elastomers, Kellogg obtained very small experimental quantities of perfluoropropene (C3F6, also known as hexafluoropropylene) and copolymerized it with VF2 to create an elastomer they believed to be superior for turbine engine O-rings. Unfortunately, the C3F6 was prohibitively expensive for Kellogg to produce or purchase. However, E. I. Dupont produced the C3F6 and made it commercially available. Concurrently in the 50s, the Air Force had been sponsoring the development of chemically resistant elastomers for aircraft engine O-rings, gaskets and seals. In 1956, E. I. Dupont approached Air Force scientists at WPAFB with the C3F6/VF2 copolymer they brand named “Viton® A”. The E. I. Dupont Company was the first to market Viton® A. Subsequently, the Air Force dropped 3M’s fluoroacrylates and Kellogg’s CTFE copolymers from consideration, the E. I. Dupont C3F6/VF2 copolymer being a superior elastomer. In 1957, Kellogg sold its process and its small factory to the 3M Company.

The 3M Company embarked into fluorochemicals in 1947-48 when they purchased the electrofluorination process (ECF) that Dr. Joe Simmons of Penn State University had developed. The ECF process was a more efficient way to produce long chain fluorocarbon molecules that are used in surfactants, textiles, paper, leather, etc. However, it was E. I. Dupont that produced the fluoropolymers in subsequent years at a lower cost. Allied Signal in the US, ICI in England, ATOChem in France, Hoechst in Germany, Asani and Daikin in Japan, and Montedison in Italy emulated the E. I. Dupont process.

In 1959, 3M took over Kellogg’s research and development of fluoroelastomers and introduced the “Fluorel” brand of fluoroelastomers, a material essentially identical to Viton® A. Until the 3M Company obtained access to low-cost monomers, 3M was at

a competitive disadvantage. This changed in the 60s and in the 70s as worldwide production of the monomers grew as C3F6, VF2, and others became more available.

Exploration of Fluorocarbon Compounds

It is fortuitous that a research group was in place at China Lake to study and develop fluorocarbon polymers. These researchers became the leaders in developing the polymer technology that later would be needed for decoy flare development.

Starting in 1950, Mr. Frank G. Crescenzo, Mr. Elmo C. Julian, and Mr. Robert C. Meyers at China Lake conducted theoretical and experimental studies of metals mixed with fluorocarbon compounds and possibly with addition of perchlorates. Their formulation studies of composition PL 6010 to PL 6085 formulae (PL stands for Pilot Lot) included magnesium, aluminum, boron, thorium, zirconium, molybdenum, and titanium as the fuels; Teflon®, lithium perchlorate, potassium perchlorate, sodium fluoride, potassium chromate as the oxidizers; and Kel®-F oil #10 as a fluorine carrier and binder. This may be the earliest record of experiments with mixtures of magnesium, Teflon®, and the fluorochlorocarbon, Kel-F® produced by 3M formerly the Kellogg company. The NOTS team also calculated the heats of reaction for the fuel-oxidizer combinations and estimated the reaction temperature. A list of composition PL numbers is included in the APPENDIX.

On 13 June 1957, Mr. Crescenzo, Mr. Julian, and Mr. Meyers of NOTS filed for a patent for an igniter composition.[5] This is an igniter for gas producing charges such as propellants, fuels, and explosives. The igniter is composed of a 30% to 85% mixture of Teflon® with Kel-F® wax; 15-70% fuels like magnesium, aluminum, boron, thorium, zirconium, and titanium; about 1-10% potassium dichromate, manganese dioxide, ammonium nitrate or ammonium perchlorate; and 1-10% lead fluoride or sodium fluoride. This work in part provided the technical foundation for the development of infrared tracking and decoy flares and may be the earliest known work related to the development of infrared decoy flares. Binary mixtures of magnesium and Teflon® to which Kel-F® wax is added as a third ingredient were first developed at China Lake in 1955. About 1959, Viton® A started to be added to the magnesium-Teflon® binary formulations in place of the Kel-F® wax.

Researchers at China Lake by 1954 were also combining fluorocarbon and chlorofluorocarbon materials with explosives. Energetic material scientists at Los Alamos National Laboratory (Panowski et al), at Lawrence Livermore (James, Scribner, et al) and at China Lake (Dr. Harold Gryting et al) were making PBX with Kel-F® elastomers and with Viton® A as binders. Knowledge of those materials provided the technological basis for their use in flares. NOTS researchers examined

[5] Crescenzo, Frank G., Elmo C. Julian, and Robert C. Meyers. Igniter Composition. U. S. Patent 3,753,811. The patent was filed on 13 June 1957, was allowed but was held under a Secrecy Order until 21 August 1973, when it issued.

explosive mixtures of magnesium powder and liquid fluorocarbon derivatives in 1954. They found that a slurry of magnesium with benzotrifluoride and fluorocarbon derivatives could be detonated by explosive shock from a #8 blasting cap. Burning rate studies of liquid fluoronitrocarbon systems continued in 1956, as did studies of magnesium-fluorocarbon-oxidizer pastes, the latter in a search for non-explosive monopropellant liquids for underwater propulsion. China Lake researchers continued to conduct fluorinated-polymer research into the mid 1960s.

On February 17, 1956, Mr. Edgar A. Cadwallader[6] of the Naval Ordnance Laboratory (NOL), White Oak Silver Springs Maryland filed for a flare composition patent The object of this invention was to make an illuminating flare by combining trifluorochloroethylene with one or more alkaline earth metals. This work is most likely connected to the ongoing target flare development tasks at China Lake in the middle 1950s.

About 1959-1962, CTFE wax (Kel-F® #40), was the binder used in infrared decoy flares being produced at NAD Crane. With the ready availability of Viton® A, it was logical that someone at China Lake or NAD Crane would try Viton® A as a binder for the binary mixture of magnesium and Teflon®. China Lake did this and Viton® A quickly became a replacement for Kel-F® wax. Because of its superior performance, Viton® A soon became the material of choice and the term MTV which stands for Magnesium/Teflon®/Viton® A became a generic acronym.

There was almost continuous work at China Lake into the mid 1960s to develop improved binders for pyrotechnics. In one such an effort, preliminary evaluation was given to a cellulose acetate butyrate rubber, a styrene-butadiene copolymer (Thermoplastic 125), and a polypropylene polymer (Vistanex®). The research team sought suitable solvents such as hexane to dissolve the rubbers to create a fluid in which solids could be dispersed. Their objective was that during extraction of the solvent and subsequent precipitation of the binder material onto the solids' surfaces, a homogeneous mixture of discrete coated particles would result. The styrene-butadiene copolymer did not coat Teflon®. In a similar way a few years later, Krayton 101 and Nordel™ 1145 binders were explored. Krayton 101 had no adhesion to a magnesium-Teflon® grain and neither did Nordel™ 1145. Estane®, a polyurethane rubber did not coat the solids when precipitated with hexane. The team determined that isopropanol, as the solvent medium is better than hexane.

During 1969 and 1970, Mr. Edward A. Allen of NOTS investigated using Vitel® polyester resin types PE-200/PE-222/PE-207, Sylgard® 182 and Sylgard® 184 dimethylsiloxane as a binder to replace the expensive Viton® A, a fluoroelastomer by E. I. Dupont. When formulated into a flare, the composition with the Vitel® polyester radiated better in the 3μm to 5μm bandpass region than in the 2μm to

[6] Cadwallader, Edgar A. Flare Composition. U. S. Patent 3,152,935. October 13, 1964. The patent was filed February 17, 1956.

3μm bandpass region. However, Viton® A performs better than Vitel® especially at simulated high altitude. The work continued in 1971 to cast flares with Sylgard® 182, potassium hexafluorophosphate, potassium perchlorate, magnesium and Teflon®. The radiant intensity was acceptable in the 3μm to 5μm bandpass region but the flare had a long burning time. Mr. Allen also tested a pressed grain with a Dow-Corning Corporation Midland Michigan product identified as FS-1265™ fluid (methyltrifluoropropylsiloxane) containing 30% fluorine, and reported that the infrared radiant intensity emitted by the flare in the 2μm to 3μm bandpass region was greater than the 3μm to 5μm bandpass region.

As a part of pyrotechnic supporting research, in June 1969 Dr. Handler, Mr. Armin Webke, Mr. F. Martinez, and Mr. D. Sbrocca of NOTS investigated the use of Vitel® and Hycar binders as a substitute for Viton® A. Vitel®, Sylgard® and Hycar™ were compared to composition PL 6328 the standard mix in the Mk 46 Mod 0 decoy flare. The team reported that a satisfactory molding powder could be made with Vitel®, which is suitable for extruding devices up to 1-inch in diameter. The best Vitel® formula is 75.2% magnesium, 13.8% Teflon®, and 11% Vitel®. This composition burns much too slowly and degrades significantly at altitude. At 35,000 feet altitude, the composition with Viton® A loses 20%, the composition with Sylgard® loses 50% and the composition with Vitel® loses 60% of its infrared radiant intensity. Degradation at high altitude is ascribed to a cooling effect and reduced pressure, which slows the reaction. About 63% magnesium is needed in the composition to sustain burning when Vitel® is used.

During 1970, China Lake investigators compared Fluon® G-3 and Halon G-10 to Teflon® #8 and Teflon® #7. Fluon® and Halon are brand names of a material similar to Teflon®. The investigators reported radiative efficiencies for Fluon® and Halon to be similar to Teflon®.

In 1971, the Teflon® supplier reported that production of Teflon® #7 and Teflon® #1 was being discontinued. This caused appreciable difficulty to infrared decoy developers. As a work-around, Teflon® #7C was considered as a substitute for Teflon® #7 in the EX 49 Mod 0 decoy flare. The formulations in the Mk 42 Mod 0 decoy flare, Mk 43 Mod 0 decoy flare, and the Mk 46 Mod 0 decoy flare were also affected because of the Teflon® #1 non-availability.

The Naval Weapons Center China Lake (NWC) reported a castable fluorocarbon binder in 1973. It consists of Viton® A, Viton® LM, and hydroxypropylmethacrylate cured with benzoyl peroxide and methylene diacrylate as a crosslinker.

During 1978-80, NAD Crane and decoy flare contractors incorporated Fluorel® FC-2175, a 3M product into their specifications as a Viton® A equivalent.

HAZARDS of ELECTROMAGNETIC RADIATION to ORDNANCE

HERO is the acronym for Hazards of Electromagnetic Radiation to Ordnance. During the late 1950s, it was known that the Mk 6 Mod 13 torpedo exploder mechanism could be set off by radio frequency (RF) energy. Also, there were aircraft carrier incidents during which Electro-Explosive Devices (EEDs) contained in ordnance were initiated while the ordnance was being loaded onto the aircraft. As a result, Emissions Control (EMCON) measures were recommended but were unpopular with the U. S. Navy because EMCON could mean loss of vital communication with planes during operations. By 1952, EMCON had been de-emphasized; but by 1956, EMCON had been changed from a recommended action to a requirement as a result of growing awareness of the need for a HERO program. Even today, Navy decoy flares and other energetic materials must meet the requirements of the HERO program.

A group of engineers, scientists, and technicians was assembled at the Naval Proving Ground (NPG), Dahlgren, Virginia to test instrumentation and techniques aboard the USS CONSTELLATION using weapon “A”. A test was conducted in March 1958 aboard the USS ROOSEVELT of 2.75-inch rockets for which there was a large “unexplained” accident/incident file. The following year, HERO was formally organized at NPG Dahlgren.

In the past, accidents with ordnance were poorly documented, especially if the cause is not easily identifiable; i.e., improper methods, physical abuse, poor techniques. Prior to the 1960s, the reporting of accidents concerning ordnance was spotty and informal. Documents that had been collected had been misplaced.

Some accidents include: (1) a 5-inch “Loki” rocket, as part of the Rockoon project, ignited on the deck of a ship in 1952. Loki is an American unguided anti-aircraft rocket based on the WW II German Taifun. Taifun means Typhoon. Loki never saw service in its original role but later found widespread use as a sounding rocket; (2) in 1957 on board the USS KEARSARGE CV33, while loading some 2.25-inch Sub-Caliber Aircraft Rockets (SCAR), one accidentally ignited causing injury to a sailor. This accident was thoroughly investigated and the cause pinpointed to a 1-kW antenna a few feet from the wing of the aircraft involved; (3) the exploder mechanism of the Mk 6 torpedo contained a detonator that on two different occasions detonated when the mechanism was being withdrawn from the torpedo. At that stage of the disassembly, a wire, acting as an antenna was exposed between the exploder and the torpedo.

These kinds of unfortunate events, along with an increasing awareness of the hazard of radio frequency (RF) energy to personnel, brought about the requirement to take corrective action and the requirement for the HERO program, still in existence today.

The HERO program and requirements are applicable to Army devices as well. In early 1960s, Picatinny Arsenal conducted a project to protect EEDs from premature initiation due to RF energy by substituting a phosphatized powdered iron-attenuating plug, an RF-absorbing material, in place of the usual plastic sealing plug. This modification was also introduced into the T24E1 Electric Detonator, M36A1 Electric Detonator, T77 conductive mix, M51 Detonators, M2 Squib, M6 Blasting Cap, the Mk 2 Mod 0 ignition element and the Mk 7 Mod 0 ignition element.

Squibs, ignition elements, and other flame producing devices are subject to accidental electrostatic discharge (ESD) or radiation hazards. In the mid 1960s, NOTS researchers explored a substitute for conventional squibs and fabricated a squib containing magnesium-Teflon®-Viton® A, which is ignited with a bridge wire. It is insensitive to electrical current (no-fire below 5 amps) and produces a 2300 - 2500 $^{\circ}$C flame.

On 29 July 1967, a fire started on board the CV29 FORRESTAL aircraft carrier caused by stray voltage, which fired a Zuni rocket from an F-4 aircraft stationed on the carrier deck. It started the conflagration and explosions.

FLARE DESCRIPTIONS

While China Lake pyrotechnicians were developing a new target augmentation flare, a target flare, a decoy flare or other devices, they assigned a “NOTS Model” designation to the device. When the developmental model later evolved into an engineering development model or a production device, the device was assigned another designation such as a Mk-Mod number. It is impressive that about sixty of these NOTS Model devices were under concurrent development in a window of only a few years.

The Army, Navy, Air Force and commercial developers had similar conventions. Often they assigned their own unique identification to their developments. And sometimes there only was a “part number” assigned related to a contract.

In several instances there is mention of a flare in the literature but only with limited or no information about the device. That explains why in a few cases herein there is a scarcity of details about a given device. In the following section, there are synoptic descriptions of a variety of decoy flares and a few others.

T-131 Tracking Flare

NOTS, China Lake was involved with infrared target augmentation since 1954. They needed a target source for the F6F-5K drone. The T-131 tracking flare developed at NOTS was the first infrared source for drone use. Six to sixteen of these are needed on the F6F-5K drone to provide a suitable signature. The grain most likely consisted of magnesium, Teflon®, and Kel-F® wax.

NOTS Model Flare series

The intent of the following descriptions is to provide a summary of information about the flare design and its intended use. When information is available, its performance capabilities are also provided. The composition of the flare grain is included when available or the composition is referenced to a composition “PL” number, the list of which is included in the Appendix.

NOTS Model 400A Decoy Flare: This flare is the forerunner to the EX 46 Mod 0 decoy flare. The NOTS Model 400A decoy flare is intended for launching from an AN/ALE-29 dispensing set. The goal is to defeat the Soviet ATOLL AA-2 air-to-air missile. The flare’s composition consists of 55% magnesium, 30% Teflon®, and 15% Viton® A. The design includes a pull wire for ignition, which is similar to pull wire igniters used in some Army devices. Mentioned in 1967 report.

NOTS Model 700: With some exceptions, the early NOTS Model 700 flares all contain Kel-F® wax as a binder. Mentioned in 1960 report. The transition from Kel-F® wax to Viton® A in flares started about 1959.

NOTS Model 701: This is a tracking flare with a composition that radiates in the visible.

NOTS Model 701A: This is a visual tracking flare that later was released as the Mk 21 Mod 0 tracking flare. The Model 702A flare supplanted the NOTS Model 701A flare because the former demonstrated superior background contrast over the NOTS Model 701A flare. The NOTS Model 701A flare grain composition is 54% magnesium, 34% sodium nitrate, and 12% Laminac®.

NOTS Model 702: This target tracking flare was designed for attachment to a target missile. The U. S. Flare Division of the Atlantic Research Corporation under a China Lake contract developed this flare. The device has a steel case of 1-inch outside diameter by 10-inches long and weighs 0.57 pounds. The load weighs 0.26 pounds (120 grams), has an output of about 300 W/sr in the 1.8μm to 2.7μm bandpass region, and has a burning time of 50 seconds. It is ignited with the Navy Mk 1 Mod 0 squib. This is the first application of a flare as a target tracking flare. Clusters of four of these flares are attached to the 5-inch High Velocity Aircraft Rocket (HVAR). The infrared grain composition in this flare is 54% magnesium, 30% Teflon®, and 16% Kel-F® wax. This formula, which has a much higher infrared radiative yield than any previous composition, was discovered in the spring of 1956. The heat of reaction is 2200 calories per gram. The peak flame temperature is in excess of 3200 K at a graybody radiation temperature of about 1800 K. The NOTS Model 702 flare evolved in 1956 from discovery of the new composition. It is the forerunner of all infrared flare decoys. Mr. George T. Hahn[7], Mr. Paul G. Rivette and Mr. Rodney G. Weldon of NOTS applied for a patent for an Infrared Tracking Flare on 27 August 1958. The infrared composition described in the patent is 54% magnesium, 23% Teflon®, and 23% Kel-F® wax. There are three versions of the NOTS Model 702 flare, these being the NOTS Model 702A flare, the NOTS Model 702B flare and the NOTS Model 702C flare. These differ only in their ignition system.

NOTS Model 702A: This target augmentation flare was developed in the spring of 1956 concurrently with the NOTS Model 700 flare. It was developed for augmentation of the signature of the F6F-5K and Ryan KDA-1 Firebee drone (one Continental J69 turbo-jet engine). No less than two NOTS Model 702A flares are used to augment the F9F-6K target per firing pass at 30,000 feet. It is initiated electrically with the Navy Mk 1 Mod 0 squib. The NOTS Model 702A flare has a 2-inch diameter steel case. The infrared composition in the flare is 54% magnesium, 23% Teflon®, and 23% Kel-F® wax. It burns for 60 seconds at ground level and 80 seconds airborne at 65,000 feet altitude. The infrared radiation from the NOTS Model 702A flare equals the infrared radiation from six NOTS Model 701A visual flares. The NOTS Model 702A flare supplanted the NOTS Model 701A flare

[7] Hahn, George T., Paul G. Rivette and Rodney G. Weldon. Infrared Tracking Flare. U. S. Patent 5,679,92127. October 21, 1997.

because it demonstrated superior background contrast over the NOTS Model 701A flare. The NOTS Model 702A flare was considered to be the Navy Tentative Standard and is interchangeable with the USFC W111B tracking flare, a commercial item made by the US Flare Corporation (USFC), Pacoima California.

NOTS Model 702B: This is a target augmentation flare that radiates in the infrared. It is ignited parasitically. Ignition is achieved by the impingement of the rocket-exhaust gases upon milled openings in the flare case, which are covered with plastic tape, on the ignition end of the flare and. The NOTS Model 702B flare was approved for production under the designation of Mk 33 Mod 0 tracking flare. Mentioned in 1960 report.

NOTS Model 702C: This target augmentation flare is a combination parasitic and squib initiated flare. Units were tested between sea level and 70,000 feet altitude and performed successfully under all conditions. Mentioned in 1960 report.

NOTS Model 703: This target augmentation flare is an experimental device developed by US Flare Corporation under Navy support. It is a slow burning flare with a Teflon® sleeve-case that enters into the reaction to add a significant amount of heat. This flare is 1-inch in diameter by 8-inches long and weighs 0.4 pounds. The grain consists of 54% magnesium, 30% Teflon® and 16% Kel-F® wax and weighs 0.1 pounds (45 grams). It has an output of about 150 W/sr in the 1.8μm to 2.7μm bandpass region, and has a burning time of 90 seconds. The benefit of a case that enters into the reaction only works for long-burning flares wherein the Teflon® has sufficient time to decompose thereby releasing the fluorine for reaction with the magnesium. The NOTS Model 702 flare contains 0.26 pounds of composition but radiates only about half the energy/gram compared to the NOTS Model 703 flare that contains one-third of the amount of composition. Cost of the Teflon® restricted its use in this application. Mr. Allen and Mr. Faldo of China Lake are credited in a 1959 report with management of the development of this flare.

NOTS Model 704: This countermeasure flare was developed by NOTS. The requirements included: (1) reliable ignition at Mach 0.5, (2) aerodynamic stability, (3) rise time within 0.5 seconds, (4) kW/sr intensity in the 2.0μm to 3.0μm region, (5) successful decoy action against an infrared seeking missile, and (6) maximum diameter of 1.5 inches. The flare went through a series of design changes from the NOTS Model 704A flare to the final NOTS Model 704K flare. The NOTS Model 704G flare, the NOTS Model 704H flare, and the NOTS Model 704K flare were built by the US Flare Corporation. The pneumatic dispenser was designed and built by the Armour Research Foundation of the Illinois Institute of Technology.

NOTS Model 704A: The original NOTS Model 704A flare is 1.5-inches in diameter by 3-inches long. The grain weighs 0.35 pounds (160 grams), has an output of about 1800 W/sr in the 1.8μm to 2.7μm bandpass region, and has a burning time of 9 seconds. This may be the first countermeasure flare to have been developed. The cross-sectional view shows a cartridge with an ogive nose, end-burning

composition in a cavity with first fire and ignition composition on the end fitted with a squib that ejects the contents. The unit is a free-falling finned device with a weighted nose. The flare composition is loaded in the aft end of the fin area. Ignition is by means of a Mk 2 Mod 0 squib that is itself initiated by the current flowing between the contact button on the back end of the flare and the flare case. Mr. Allen and Mr. Faldo of China Lake are credited in a 1959 report with the development of this flare.

NOTS Model 704B: This variant is an enlarged version of the NOTS Model 704A flare, which increased the burning time but gave little advantage on a relative weight basis.

NOTS Model 704C: This variant used a Teflon® sleeve to contain the flare material. It did not prove effective.

NOTS Model 704D: This variant involves an ignition design study to reduce damage to the squib wiring by the windstream.

NOTS Model 704E: This variant involved a change in the fin size from 0.5 inches to 0.75 inches to improve aerodynamic stability. This design change was retained in subsequent models.

NOTS Model 704F: This variant consisted of a replacement of the granulation of the magnesium from gran 15 (100-200 mesh) to gran 16 (200-325 mesh). This resulted in an increase in intensity with a shorter burning time. It was adopted to compensate for altitude and windstream losses.

NOTS Model 704G: In this variant the original solid cone shaped nose was replaced with a hollow ogive shape. Stability was improved and assembly was simplified by this change.

NOTS Model 704H: This variant combines the composition of the NOTS Model 704F flare and the configuration of the NOTS Model 704G flare. Flare production and dispenser development contracts to US Flare Corporation and the Armour Research Foundation of the Illinois Institute of Technology were based on this design. This flare is 1.5 inches in diameter by 3 inches long. It has an ogive front end with 4-fins aft. All parts are made from iron. The weight is 1.65 pounds (750 grams). The unit, which is ignited at the aft end, burns for 8 seconds and contains 0.2 pounds (90 grams) of flare composition consisting of 18% magnesium gran 15 (100-200 mesh), 36% magnesium gran 16 (200-325 mesh), 30% Teflon® #1 (30-50 mesh), and 16%, Kel-F® #40 wax.

NOTS Model 704J: This variant incorporates an improved squib assembly and mechanical changes to prevent the nose cone from separating from the flare.

NOTS Model 704K: This is the final version. It includes a composition change recommended by US Flare Corporation based on studies conducted during the NOTS Model 704H flare developments. This target flare is 1.5 inches in diameter by 3 inches long. It has an ogive front end with four 0.75-inch long fins aft. The case is a finned stainless steel cylinder with ogive nose cone. The device weight is 1.66 pounds (750 grams). The unit is ignited at the aft end, burns for 10 seconds and contains 0.36 pounds (163 grams) of flare composition consisting of 18% magnesium gran 15 (100-200 mesh), 36% magnesium gran 16 (200-325 mesh), 30% Teflon® #1 (30-50 mesh), and 16%, Kel-F® #40 wax.

NOTS Model 705: This series of target augmentation flares was developed for drone augmentation. They also are used on the Pogo-Hi rocket. The various electrically ignited versions differ principally in their burning times and radiant intensities. The NOTS Model 705A flare has been shown to ignite and burn at 60,000 feet altitude. This steel cased device is 2.25 inches in diameter by 9.5 inches long and weighs 3.53 pounds. The grain consists of 54% magnesium, 30% Teflon® and 16% Kel-F® wax.

NOTS Model 706: This is a tracking flare with a composition that radiates in the visible. Mentioned in 1960 report.

NOTS Model 707: The NOTS Model 707 flare, developed by NOTS, was designed as a high altitude visible tracking flare to augment the Sidewinder 1-C missile signal. It also is used to augment the signature of the Vought KD2U-1 Regulus II drone (one GE J33 jet engine). This drone is larger than the Ryan KDA-1 Firebee drone and consequently needs more flares. The NOTS Model 707 flare was one of the subjects of an elaborate early attempt to establish a correlation between flare burning time performance, composition, and construction of various flares. The device is 1 inch in diameter by 24 inches long and weighs 1.48 pounds. It is ignited parasitically. The grain is assembled into a stainless steel case. The grain consists of 54% magnesium, 30% Teflon® and 16% Kel-F® wax.

NOTS Model 707A: This is the tracking flare mounted on the Sidewinder 1C missile. The flare must operate at 80,000 feet altitude. The flare is about 1-inch in diameter. It radiates about 300,000 candela in the visible region for 30 seconds when tested at ground level.

NOTS Model 709: This is a tracking flare with a composition that radiates in the visible. Mentioned in 1960 report.

NOTS Model 710: This target augmentation flare, designed by NOTS, is enclosed in a Teflon® sleeve that probably contributes to the efficiency of the flare's performance under ground test conditions. However, under experimental flight tests, the low friction between the Teflon® sleeve and the pellet led to grain separation. To overcome this deficiency, a metal sleeve was substituted and performance was then acceptable to 30,000 feet altitude. The flare is ignited

electrically and is used to augment drone signatures. The device is 2 inches in diameter by 9.75 inches long and weighs 1.85 pounds. The grain consists of 54% magnesium, 30% Teflon® and 16% Kel-F® wax.

NOTS Model 711: This target augmentation flare is in a plastic case and is used to augment the radiative signature of target drones. The Air Force nomenclature for this flare is TAU-15/B. Some references state that the TAU-15/B infrared tracking flare is the Air Force tentative standard of the NOTS Model 711A flare. Mentioned in 1960 report. This target flare was developed by NOTS in response to an Air Force Interservice request to China Lake for the production of 500 target flares of defined characteristics in terms of size, radiant energy and altitude performance. The flare was designed and fabricated with a modified manufacturing procedure using the NOTS Model 702A target flare composition. The initial configuration delivered to the Air Force is designated the TAU-15/B flare. The Navy modification is designated the MK 28 Mod 0 flare. The grain is assembled into a Micarta phenolic case. Ignition is performed electrically with the Mk 2 Mod 0 squib. The device is 1.93 inches in diameter by 9.5 inches long and weighs 1.5 pounds. The grain consists of 54% magnesium, 30% Teflon® and 16% Kel-F® wax. The first fire is a mixture of 90% barium chromate and 10% boron powder.

NOTS Model 711A: This target augmentation flare is in a plastic case and is the first flare used for evaluation of weapon systems. The developmental objective of this flare is to provide infrared augmentation to Air Force aerial tow targets and drone aircraft. The USN also used it on drone aircraft, target rockets, and aerial towed targets to provide better evaluation tests for the Sidewinder and Falcon missiles. This target flare was mounted on an F6F-5K aircraft. The Prototype Production for Evaluation (PPE) of this flare was conducted at NAD Crane. The NOTS Model 711A flare aka the TAU-15/B infrared tracking flare evolved into the Mk 28 Mod 0 target flare. Mentioned in 1960 report.

NOTS Model 712: This target augmentation flare is in a plastic case and is mounted on the wing tip of fighter aircraft that are configured as a drone. The airborne burning time is 120 seconds. Mentioned in 1960 report.

NOTS Model 712A: This electrically ignited device, developed by NOTS, is used as a target augmentation flare for testing the increased range Sidewinder 1C missile. It is attached to the QF-9F target drone, the Beech Aircraft KDB drone or the Ryan target drone BQM-34A (old designation Q2C) jet powered aerial target with a subsonic speed. The flare has an airborne burning time of 60 seconds and when airborne radiates 1300 W/sr in the 2μm to 3μm bandpass region. On the ground, it radiates about 2000 W/sr in the 2μm to 3μm bandpass region for about 45 seconds. The device is 2-inches in diameter by 12 inches long and weighs 2.36 pounds. The composition contains 54% magnesium gran 15, 30% Teflon® no. 1, and 16% Kel-F® #40 wax. Its phenolic case eliminates the problem of molten metallic particles dripping from the case during combustion. The flares for a missile test were loaded at the Naval Ordnance Plant in Macon Georgia. During a conference in 1960, Mr.

James H. Pennington of China Lake stated that the NOTS Model 712A flare would become the NOTS standard target source for most target drones. The NOTS Model 726C flare replaced the NOTS Model 712A flare. Mr. Allen of China Lake was involved in the development of the NOTS Model 712A flare.

NOTS Model 712C: This target augmentation flare is parasitically ignited.

NOTS Model 712E: This target augmentation device has greater reliability, increased radiancy, and improved altitude performance compared to the NOTS Model 712 flare and the Flare-Northern W211S flare. The NOTS Model 712E flare also has increased output and storage life. It uses NOTS Model 712A flare hardware and has Viton® A in the composition. Compared to the NOTS Model 712A flare, the NOTS Model 712E flare burns much longer and the radiative output in the 2μm to 3μm bandpass region is almost double at 60,000 feet altitude. Its infrared signal is sufficient for Sidewinder 1C missile firings at high altitudes and long standoff ranges. The composition contains 54% magnesium gran 16, 30% Teflon® no. 1, and 16% Viton® A. This flare composition is reported to be extremely resistant to moisture deterioration and is readily ignitable at high altitude. Initiation is with a NOTS Model 39A pyrogen squib or E. I. Dupont E-92 blasting cap. It does not have an intermediate ignition composition or first fire composition.

NOTS Model 713A: This is a high altitude flare for the Sparrow III missile, which was developed by the Bermite Powder Company, Saugus California for the Navy Bureau of Ordnance during 1960. This parasitically ignited flare emits 200,000 candela and has a burning time of 30 seconds at 70,000 feet, the operational altitude. The flare contains 245 grams of illuminating composition consisting, in parts by weight, of 60 parts gran 17 atomized magnesium, 5 parts gran 16 atomized magnesium, 40 parts sodium nitrate, and 5 parts Laminac® polyester binder catalyzed with Lupersol™ DDM. The first fire is a mixture of 10% boron and 90% barium chromate. The complete flare weighs about one pound and is two inches in diameter by four inches long.

NOTS Model 714A: This is a Bullpup missile parasitic tracking flare designed for visual tracking. It was developed as a result of a 1957 directive from Navy Headquarters in Washington DC. It replaces the Mk 23 Mod 0 electric tracking flare. The cartridge is 1.75 inches diameter by 6 inches long with a cartridge wall thickness of 0.5 inches. It burns about 47 seconds with visible intensity of 140,000 candela in the first 10-12 seconds and 225,000 candela thereafter. The high-intensity composition is a mixture of strontium nitrate, sodium nitrate, magnesium, and Laminac® 4116, the latter being a polyester binder. For low-intensity, hexachlorobenzene is added and potassium nitrate replaces the sodium nitrate. This flare evolved into the Mk 27 Mod 0 tracking flare.

NOTS Model 715B: This target flare was developed by NOTS to fit the AN/ALE-18 pneumatic chaff dispenser installed on A3-D, A3-J, and F4-D aircraft. The 0.63-pound (285 gram) flare pellet is extruded into a wedge shape of 3.65 inches by 2.7

inches by 1.05 inches thick, which tapers to 0.34 inches thick. An ignition composition is buttered on all surfaces. It is initiated with a NOTS Model 668A stab primer. The flare burns about 8 seconds. The magnesium-Teflon®-Kel-F® wax flare mixture had inadequate physical properties when extruded which caused a composition change to composition PL 6239: 54% magnesium gran 16, 30% Teflon® #7, and 16% Viton® A. The device weight is 0.8 pounds (370 grams). About 35 composition variants were evaluated during the flare development. Granular sizes of the magnesium and Teflon® were the main parameters varied in the study. Mr. Allen and Mr. B. A. Breslow of China Lake reported this flare in 1964. The NOTS Model 715B flare evolved into the Mk 43 Mod 0 flare.

NOTS Model 717B: Flare. No further information was found.

NOTS Model 719: This target augmentation flare, developed by NOTS, is a cylindrical aluminum cased flare developed for use with the Sidewinder 1C missile. It was tested in flight at altitudes up to 50,000 feet. The device is 1 inch in diameter by 18 inches long. The grain consists of 54% magnesium, 30% Teflon® and 16% Kel-F® wax.

NOTS Model 720: This target augmentation flare, developed by NOTS, was intended for use on the Radioplane XKD4R-1 target drone. The flare is assembled in a phenolic ablation sleeve in sets of four, which burn consecutively to provide a signal of the required duration. Each flare actuates a thermal switch as it approaches burnout, to initiate the next flare. The device is 1.35 inches in diameter by 11 inches long. The grain consists of 54% magnesium, 30% Teflon® and 16% Kel-F® wax.

NOTS Model 723: This target augmentation flare, developed by NOTS China Lake before 1974, is one of the largest magnesium-Teflon® flares ever constructed. Only two flares were ever built. The units are ignited electrically. Viewed in a vertical static test, the flare yielded 186 kW/sr over a 60 second period. There is no case material. The device is 12 inches in diameter by 16 inches long and weighs 70 pounds. The grain consists of 54% magnesium, 30% Teflon® and 16% Viton® A.

NOTS Model 724A: This is a curved tracking flare whose special design shape was requested by NOL White Oak in the mid 1960s. The flare is needed for tracking and recovery of a canister. It has a 30 second burning time and produces 16,000 candela at 65,000 feet altitude for visual tracking. The curved shape saves space in the canister. The flare fits into and marks the path of an instrumentation package that is ejected from a missile at altitudes up to 100,000 feet altitude. Initiation is by a hand grenade bouchon. Its predecessor is the NOTS Model 739A flare. Another reference describes this curved flare as the NOTS Model 742 flare. The latter seems more likely since the curved flare design is a follow-on to the NOTS Model 739A, the NOTS Model 742 being numerically more logical to be a follow-on to the NOTS Model 739.

NOTS Model 726 series: This target augmentation flare is a wing tip target flare developed to augment the QF-9C target drone and the Q-2C target drone for the Sidewinder 1C missile. This flare is also identified with the Beech KDB drone. It was designed for operation at 50,000 feet and Mach 0.9. The NOTS Model 726A flare and the NOTS Model 726B flare differ both in size and composition, the NOTS Model 726B flare possessing twice the burning rate of the NOTS Model 726A flare with a correspondingly higher radiant intensity.

NOTS Model 726A: This target augmentation flare was developed under the guidance of Mr. Allen of China Lake to satisfy the need for increased radiation and better high altitude performance when attached to a QF-9F target drone or a BQM-34A (old designation Q2C) jet powered aerial target operating at subsonic speed. The flare is used to test the Sidewinder 1C missile. It was designed to perform at Mach 0.9 and at 50,000 feet altitude. The flare needed to perform better than the NOTS Model 712A flare or the Flare-Northern W211S flare. It has a one-piece extruded grain that has a composition formula different from that in the NOTS Model 726B flare. It is two-inches in diameter by 12 inches long and is electrically ignited. Extrusion of the grain in comparison to pressing the grain eliminated output fluctuations and ejection of increments. The burning time is about 4 minutes at 30,000-feet altitude. The NOTS Model 726A flare, NOTS Model 726B flare, and NOTS Model 726C flare differ in the type of Teflon® used. Each is inhibited with a different material.

NOTS Model 726B: This target augmentation flare was developed under the guidance of Mr. Allen of China Lake to satisfy the need for increased radiation and better high altitude performance when attached to a QF-9F target drone or a BQM-34A (old designation Q2C) target drone. The flare has a one-piece extruded grain that has a formula different from that in the NOTS Model 726A flare or the NOTS Model 726C flare. It is 2.25 inches in diameter by 8 inches long and is electrically ignited. It uses a NOTS Model 39A pyrogen squib to get better very high altitude ignition. The NOTS Model 726B flare was produced at the Navy Propellant Plant (NPP), Indian Head Maryland and was programmed to replace the NOTS Model 712A flare. However, the cast polyester inhibitor proved inadequate for flight when one was observed to break apart. The burning rate is twice that of the NOTS Model 726A flare and emits twice the amount of infrared radiation. The NOTS Model 726A flare, the NOTS Model 726B flare, and the NOTS Model 726C flares differ in the type of Teflon® used. Each is inhibited with a different material.

NOTS Model 726C: This target augmentation flare was developed under the guidance of Mr. Allen of China Lake to satisfy the need for increased radiation and better high altitude performance when attached to a QF-9F target drone or a BQM-34A (old designation Q2C) jet powered aerial target operating at subsonic speed. The flare is used to test the Sidewinder 1C missile. It was designed to perform at Mach 0.9 and at 50,000 feet altitude. The flare needed to perform better than the NOTS Model 712A flare or the Flare-Northern W211S flare. After evaluation, it was determined that the NOTS Model 726C flare design would replace the NOTS Model

712A target augmentation flare because the former does not eject burning materials during operation. The NOTS Model 726C flare has a one-piece extruded grain and a composition formula different from that in the NOTS Model 726A flare or the NOTS Model 726B flare. It is 2.16 inches in diameter by 12 inches long and is electrically ignited. At ground level, the NOTS Model 726C flare burns about 40 seconds. The NOTS Model 726A flare, the NOTS Model 726B flare, and the NOTS Model 726C flares differ in the type of Teflon® used. Each was inhibited with a different material. The inhibitor on the NOTS Model 726C flare is glass cloth and Ethocel tape. The production quantities were made at the Navy Propellant Plant, Indian Head Maryland.

NOTS Model 727: The NOTS Model 727 target augmentation flare, developed by NOTS, is wing tip mounted on the Curtis Wright Skydart drone. The unit is 2 inches in diameter by 10 inches long. The grain consists of 54% magnesium, 30% Teflon® and 16% Kel-F® wax.

NOTS Model 728A: This is a ballistic target rocket flare used in Sidewinder 1C tests. The device is designed for high altitude performance. This model is electrically ignited and packaged in a 2-inch diameter by 12-inch long case. The grain consists of 54% magnesium, 30% Teflon® and 16% Kel-F® wax. At ground level, it radiates about 2000 W/sr in the 2μm to 3μm bandpass region for about 30 seconds. At an altitude of 60,000 feet, it burns for 60 to 65 seconds.

NOTS Model 728B: This is a ballistic target rocket flare used in Sidewinder 1C tests. The device is designed for high altitude performance. This model is parasitically ignited and is packaged in a 2-inch diameter by 12-inch long case. The grain consists of 54% magnesium, 30% Teflon® and 16% Kel-F® wax. At ground level, it radiates about 2000 W/sr in the 2μm to 3μm bandpass region for about 30 seconds. At an altitude of 60,000 feet, it burns for 60 to 65 seconds. This variant was launched vertically at 47,000 feet altitude from an F-4 aircraft and functioned successfully up to 82,000 feet altitude.

NOTS Model 729: The NOTS Model 729 target augmentation flare, designed by NOTS, was initially developed as an augmentation flare for use with the Beech XKD2B-1 target drone. It was designed for sustained operation at high altitude (70,000 feet). This flare is intended to replace the 5B1-5.1 Special Devices infrared target augmentation flare made by Special Devices Incorporated, Newhall, California for a Beech Aircraft Corporation Navy drone. The Beech Aircraft Corporation's XKD2B-1 Navy drone later became the AQM-37A expendable powered target drone. At 70,000 feet altitude, the flare is required to provide ample infrared radiation in the 2μm to 3μm and 3μm to 5μm electromagnetic bands for 8 minutes. Test failures of the NOTS Model 729 flare lead to development of improved models. China Lake was requested by Navy Headquarters in Washington DC to develop a backup to the Special Devices 5B1-5.1 flare in the event that the latter did not meet requirements. The resulting three developmental models are:

NOTS Model 729A flare uses composition PL 6239.
NOTS Model 729B flare uses composition PL 6328.
NOTS Model 729C flare uses composition PL 6382.

The improved models also differ in the type to Teflon® used. The composition in each is extruded to form the grain. The ignition mixture and first fire composition consist of a mixture of 10% boron and 90% barium chromate. Of the three compositions, the NOTS Model 729B flare was selected for further development on the basis of high altitude performance.

NOTS Model 729B: This is a target augmentation flare for the AQM-37A target drone. It was developed as a back up to the commercially manufactured infrared flare, the Mk 37 Mod 0 tracking flare. It is 20.25 inches long by 2.5 inches in diameter. Because of its 20.25-inch length, the flare mounting incorporates a constant force spring that advances the flare grain continuously as it burns. The grain, which is extruded MTV, is inhibited with a spiral wrap of ethyl cellulose tape. The grain is formulated with composition PL 6328. The first fire is a mixture of 10% boron and 90% barium chromate. Ignition is accomplished electrically. The NOTS Model 729B flare, as compared to the NOTS Model 729A flare and the NOTS Model 729C flare, has the fastest burning rate at 70,000 feet altitude with the greatest output in the 2µm to 3µm bandpass region. The NOTS Model 729B flare is similar in configuration to the Mk 37 Mod 0 flare but not in composition.

NOTS Model 733A: This target flare was developed about 1962 under the guidance of Mr. Allen of China Lake as an infrared flare to protect the Ryan BQM-34A jet powered aerial target drone. A specific requirement was that the flare must ignite and burn at very high altitude and high subsonic Mach number. In addition, the flare needs to be compatible with the Lundy Model RC17-101 mechanically operated miniature chaff dispenser and the electrically operated Lundy Model 30-0011-2 chaff dispenser that were installed in either wing of the BQM-34A aerial target. These dispensers originally were designed to dispense RR-72 flare cartridges. The NOTS Model 733A flare is also compatible with the AN/ALE-33 dispenser. The flare format, similar to the RR-72 flare cartridge, is extruded in a rectilinear shape 4.875 inches long by 3 inches wide by 1.031 inches thick. The flare weighs 0.725 pounds. The grain is composition PL 6328. Ignition takes place over the entire surface area. At 47,000 feet altitude and Mach 0.86, the grain burns for about 6 seconds. To obtain reliable ignition, a wind-removable pull-away tab device operated by the air stream activates the NOTS Model 668A stab-initiated primer, which in turn ignites the intermediary Z-2 heat paper and that in turn ignites the extruded grain. The NOTS Model 733A flare exceeds the output and burning time required for operation at 50,000 feet altitude. Release to Prototype Production for Evaluation occurred in June 1965. It became the Mk 42 Mod 0 target flare.

NOTS Model 733B: This target flare was developed in the mid 1960s to fit a chaff dispenser on the BQM-34A (Q-2C) target drone.

NOTS Model 736: This cylindrical target augmentation flare, fabricated by NOTS, is a target flare for use with the Redeye missile. The flare is 0.56 inches in diameter by 8.75 inches long. The grain consists of 54% magnesium, 30% Teflon® and 16% Viton® A.

NOTS Model 737: This cylindrical target augmentation flare, fabricated by NOTS, is a target flare for the Redeye missile. The grain consists of 54% magnesium, 30% Teflon® and 16% Viton® A. The flare is 0.79 inches in diameter by 8.75 inches long.

NOTS Model 739A: In the mid 1960s, NOL White Oak requested the design of a flare for tracking and recovery of a canister containing an instrumentation package. It was made to fit into and mark the path of an instrumentation package ejected from a Blue Rock missile at altitudes up to 100,000 feet. The flare is 1 inch in diameter by 10 inches long. The grain consists of 54% magnesium, 30% Teflon® and 16% Viton® A. Later a curve-shaped flare, the NOTS Model 724 flare, was developed to save space in the canister. Another reference states the follow-on is the NOTS Model 742 flare, which most likely is the correct nomenclature.

NOTS Model 740: This cylindrical target augmentation flare, fabricated by NOTS, is a modified NOTS Model 737 flare designed for use as a Redeye missile target. The NOTS Model 740 flare incorporates a tubular steel shield to suppress visible radiation. The flare is 0.79 inches in diameter by 8.75 inches long. The grain consists of 54% magnesium, 30% Teflon® and 16% Viton® A.

NOTS Model 741: This cylindrical target augmentation flare, fabricated by NOTS, is a target flare designed for use as a Redeye missile target. The NOTS Model 741 flare incorporates a tubular steel shield to suppress visible radiation. It is similar in composition to the NOTS Model 737 flare but has the shield design of the NOTS Model 740 flare. The flare is 1 inch in diameter by 36 inches long. The grain consists of 54% magnesium, 30% Teflon® and 16% Viton® A.

NOTS Model 742: In the mid 1960s, NOL White Oak requested the design of a flare for tracking and recovery of a canister containing an instrumentation package. That earlier design is the NOTS Model 739A flare.

Later a curve-shaped flare, perhaps erroneously designated the NOTS Model 724A flare, was developed to save space in the canister. Another reference describes this curved flare as the NOTS Model 742 flare. The latter designation seems more likely since the curved flare design is a follow-on to the NOTS Model 739A, the Model NOTS 742 being numerically more logical to be a follow-on to the NOTS Model 739.

NOTS fabricated this curved-shaped tracking flare, the NOTS Model 742 flare. It was made to fit into and mark the path of an instrumentation package ejected from a Blue Ridge missile at altitudes up to 100,000 feet. It has a 30 second burning time

and produces 16,000 candela at 65,000 feet altitude for visual tracking. The curved shape of the flare saves space in the canister. Initiation is by a hand grenade bouchon. The flare is configured as a 10-inch long by 1-inch diameter cylinder that is curved in a 115-degree arc in about a 5-inch radius. This curved cylinder contains a grain that consists of 54% magnesium, 30% Teflon® and 16% Viton® A.

NOTS Model 743: This is a tracking flare for the anti-radiation AGM-45A Shrike missile to obtain missile trajectory. It is marginal in the required luminosity.

NOTS Model 743A: This tracking flare is intended for use on the anti-radiation AGM-45A Shrike missile to obtain missile trajectory. The case is an 11-inch long aluminum tube of 1-inch outer diameter and 0.930 inch inside diameter. It contains an extruded grain with composition PL 6239. This unit was evaluated for use on the Shrike missile because of problems with the commercial W114B tracking flare.

NOTS Model 743B: This tracking flare is intended for use on the anti-radiation AGM-45A Shrike missile to obtain missile trajectory. The case is an 11-inch long mild-steel tube of 1-inch outer diameter and 0.930 inch inside diameter. It contains an extruded grain with composition PL 6239. This unit was evaluated for use on the Shrike missile because of problems with the commercial W114B tracking flare.

NOTS Model 744: This tracking flare has more luminosity than the NOTS Model 743 flare.

NOTS Model 745: This tracking flare is larger in diameter and has an increased radiancy over the NOTS Model 743 flare and the NOTS Model 744 flare.

NOTS Model F28-1: This is an MTV target flare mounted on the AQM-37 non-recoverable drone. The flare faces forward into the windstream and is ignited at Mach 1.5 at 60,000 feet altitude. It has a burning time of 90 seconds. Four flares are burned simultaneously to obtain the required intensity levels. The external dimensions are 2 inches in diameter by 23 inches long. The grain composition is 63% magnesium, 10% graphite, 13.5% Teflon® #7, and 13.5% Viton® A.

NWC Model F28-2: This decoy flare incorporates the latest advances in igniter and grain design resulting from the EX 49 Mod 0 flare development. The NWC Model F28-2 flare is compatible with the AN/ALE-29A dispenser and the AN/ALE-39 dispenser and is designed to be a flare with the burning time and radiant intensity needed by medium performance attack aircraft in a low altitude, high-subsonic-flight-speed environment. The change from the NOTS Model designation to the NWC Model designation most likely is the result of the name change of China Lake from NOTS to NWC about 1969.

NOTS Model F28-2A: This MTV countermeasure flare is similar in physical dimensions to the Mk 49 Mod 0 flare. A modified formula is used to increase the burning time by a factor of two over the Mk 49 Mod 0 flare. The external dimensions

are 1.42 inches in diameter by 5.8 inches long. The flare weighs 0.52 pounds. The grain dimensions are 1.33 inches in diameter by 4.87 inches long. The grain weighs 0.34 pounds.

NOTS Model F28-2B: This experimental MTV countermeasure flare is dimensionally identical to the NOTS Model F28-2A flare but with a different unspecified composition to modify the burning time.

NWC 45/01 Countermeasure Flare: The NWC 45/01 flare is a revisited version of the Mk 49 Mod 0 flare. The configuration resembles the spaghetti flare design of the MK 49 Mod 0 flare but is much larger. It is stated to have a very fast rise time, a high infrared intensity and a 50% longer burning time than the Mk 49 Mod 0 flare. The grain consists of 63% magnesium, 13.7% Teflon® #7, 10% graphite and 13.5% Viton® A. The grain is 2.88 inches in diameter by 8.37 inches long and weighs 2.7 pounds.

Navy Mini-Flare: The Navy mini-flare is similar in configuration and intended application to the Army XM-196 mini-flare. The MTV formula in the Navy flare is different from that in the Army mini-flare. The design was not released for procurement. The external dimensions are 1.05 inches in diameter by 2.63 inches long. The device weighs 0.21 pounds. The grain dimensions are 0.94 inches in diameter by 1.88 inches long. The grain weighs 0.066 pounds. Slightly different dimensions appear in other reports. The grain formula is 54% magnesium, 30% Teflon® and 16% Viton® A. The composition is pressed to make the grain. The development of the Navy mini-flare is described in more detail in the section entitled Mini-Flare Development.

UK Flare

UK Mk 1 Decoy (an earlier UK designation is Flare Type E/2/1): The UK decoy unit identified as Flare Type E/2/1 later became the UK Mk 1 Decoy about March 1963. It is 2.25 inches in diameter by 5.3 inches long. The 1962 vintage units contain a safe and arming device (S&A). The grain infrared composition consists of 55% magnesium and 45% Teflon®. There is no binder in this composition. Without a binder, this composition cannot be extruded but must be pressed to form the grain. The grain has longitudinal grooves on the outer surface. When ignited, it produces a rise time to peak intensity of 0.5 seconds.

Army Devices

M-50 Tow Target Flare: This Army flare provides a target for both night and day practice firing of antiaircraft guns. It is 22.8 inches in length by 2.62 inches in diameter and weighs 7.13 pounds.

M-76 Airport Flare: This Army flare is 31.33 inches long by 4.26 inches in diameter and weighs 27.6 pounds. It contains 20-pounds of illuminating composition. It is used for illumination of aircraft landings in case of power failure at the airport.

M-112 Cartridge: The case of this cartridge was used as the test vehicle for the development of the RR-77 flare. The M-112 cartridge designation normally is associated with a photoflash cartridge. It is 1.57 inches in diameter by 7.73 inches long.

M136 (T131) Tracking Flare: The M136 flare has a laminated phenolic body and an aluminum shank. The illuminating composition in the flare produces 70,000 candela for 75 seconds.

M-206 Aircraft Decoy Flare: This is an Army flare, which nominally is 1-inch by 1-inch by 8-inches in size. It is used by both fixed and rotary-wing aircraft.

XM-196 Mini-Flare (Army): This is the designation for the experimental mini-flare assigned by the Army. The MTV composition is pressed to make the grain. A Picatinny Arsenal task under an Electronics Command, Fort Monmouth directive calls for the development of the Army mini-flare. Tracor developed the decoy system with the flare production assigned to the Pace Corporation. The flare dispenser contains 154 flares. The Army mini-flare has a fast rise time and tends to show two peaks, the normal one at maximum radiant intensity and the other one at burnout. The burnout peak is attributed to disintegration of the flare with the exposure of a large reactive surface. The Army mini-flare is a precursor of the Navy mini-flare, which is somewhat similar in design. The external dimensions of the flare are 1.05 inches in diameter by 2.75 inches long. It weighs 0.16 pounds. The grain dimensions of the flare are 0.94 inches in diameter by 1.88 inches long. It weighs 0.066 pounds. Two Picatinny Arsenal compositions are pressed in the case as a single increment. The two compositions, in parts by weight, are: (1) 74 parts magnesium, 26 parts Teflon®, and 2.6 parts Viton® A; and (2) 74 parts magnesium, 26 parts Teflon®, and 2.6 parts nitrocellulose.

XM-197 Decoy Flare: Picatinny Arsenal developed this flare designed for release from the hand-held AN-M8 pyrotechnic pistol. This MTV Army Flare is similar to the Mk 50 Mod 0 flare. The device is 1.57 inches in diameter by 3.85 inches long. The grain is 1.25 inches in diameter by 2.4 inches long.

33-18 Flare: This is an Army developmental flare intended for ship protection.

Air Force Flares

ALE-11 Flare: The grain in this flare is MTV. It is available in two configurations; 1 inch by 3 inches by 5 inches and 2 inches by 3 inches by 5 inches.

ALE-11 Flare, Cast Variant: This experimental flare variant was manufactured about 1966 at Flare-Northern Division of the Atlantic Research Corporation Saugus California by Dr. Hal R. Waite and Mr. Jerry A. Reed for the AN/ALE-25 Dispenser. The flare weighs 2.2 pounds, incorporates a mechanical safe-and-arm initiator, and is loaded with a castable fluoromethacrylate-magnesium composition.

ALA-17 Flare: This is an MTV flare that evolved from the RITA-II flare, which has a similar composition but is fractionally smaller in diameter. Picatinny Arsenal developed the ALA-17 flare for the Air Force. The FW-306 infrared composition is pressed to make the grain that is about 2.4 inches in diameter and 4.9 inches long. The ALA-17 flare is about 2.5 inches in diameter by 5 inches long and weighs 1.3 pounds. The ALA-17 flare rise time of two seconds to reach 75% of peak is considered to be too long. This flare is dispensed from an AN/ALE-14 countermeasure flare ejector mounted in the B-52 bomber.

ALA-17 Flare, Improved Cast Variant: The improved ALE-17 flare for the AN/ALE-20 ejector set was developed by Dr. Waite and Mr. Reed of Flare-Northern during 1966. An internal burning grain is cast directly into an aluminum case, and, unlike the standard ALA-17 flare, it remains within the case while burning. The core design is a regressive burning internal star. Fluoroalkylmethacrylate is the casting resin.

ALA-34 flare: This is an MTV flare that contains infrared composition FW-306. The grain for the ALA-34 flare carries the designation RR-138 grain. The goal is to reach nominally 2000 W/sr in 0.1 seconds and a peak of about 5000 W/sr in 0.3 seconds. The ALA-34 flare is a B-52 flare designed to be dispensed from the AN/ALE-20 Flare Dispenser. There are two variants. One variant designated ALA-34 DL is 10 inches long, twice the length of the ALE-17 flare and 2.4 inches in diameter. In this variant, the grain has a smooth surface. The other variant designated ALA-34G has a larger diameter of 2.66 inches by 4.9 inches long and has a grain with 26 grooves milled along the longitudinal surface. These groves are filled with an igniter composition. The grooved version exhibited a significantly faster rise time while the double length version exhibited significantly more radiant intensity than the ALA-17 standard flare. Mr. Charles A. Knapp of Picatinny Arsenal initiated the decoy designs under a contract from Eglin Air Force Base.

RR-72 Decoy Flare: The external configuration is similar to the NOTS Model 733A target flare.

RR-77 Decoy Flare: Multiple RR-77 flares are assembled into the cartridge. The cartridge is placed into the assembly housing of the AN/ALE-14 ejector system. The latter is installed in bomber aircraft. The flares in the cartridge are ejected

sequentially. RITA flare technology utilizing infrared compositions is used for the RR-77 flare development.

RR-78/ALE Flare Ejector: This ejector is believed to be the RITA flare battery dispenser.

RR-80 Decoy Flare: This flare is designed for use with the AN/ALE-14 dispenser in the B-47 bomber and the AN/ALE-20 dispenser in the B-52 bomber. The composition in the RR-80 flare consists of 66.1% magnesium RMC200, 22.6% Teflon® #5, and 11.3% Teflon® #7. There is no binder in this formulation. The composition is pressed into pellets 4.469 inches long by 2 inches in diameter. The pellets are encased in a polyurethane foam inhibitor. The RR-80 flare consists of two pellets, which in total weigh 1.79 pounds. The flare external dimensions are 2.25 inches in diameter by 10 inches long. The total device weight is 2.63 pounds. The flare pellets burn simultaneously on each end (double ended burning). The burning time at ground level is 25 seconds. Dr. Sidney Katz, Armour Research Foundation of the Illinois Institute of Technology, Chicago developed the RR-80 flare, which is assembled into the RR-80/ALE flare assembly. The latter has 8 tubes and one RR-80 flare per tube yielding a total of eight flares per assembly. The flare assembly ejector set is the RR-80(XY)/ALE which is compatible with the AN/ALE-14 ejector system and AN/ALE-20 ejector systems.

RR-81 Decoy Flare: This flare is compatible with the AN/ALE-14 dispenser and the AN/ALE-20 dispenser in the B-47 bomber and the B-52 bomber respectively. The RR-81 flare pellet is about 1.875 inches in diameter by 5.75 inches long and contains a composition, in parts by weight, of 31 parts magnesium, 59 parts Teflon®, and 19 parts titanium to which 34 grams of Kel-F® wax is added as a binder. The flare pellet burns simultaneously from the middle toward each end causing the two flames to impinge upon each other. (Opposed end burning) The burning time at ground level is 17 seconds. Kilgore, Incorporated developed the flare. The RR-81 flare is assembled into the RR-81(XY-1)/ALE flare assembly, which has seventeen 11.5-inch tubes and 2 flares per tube.

RR-82 Decoy Flare: This flare is compatible with the AN/ALE-14 dispenser and the AN/ALE-20 dispenser in the B-47 bomber and the B-52 bomber respectively. The RR-82 flare is about 1.88 inches in diameter by 11 inches long and contains a composition consisting, in parts by weight, of 50 parts magnesium, 40 parts Teflon®, and 10 parts titanium. The flare pellet only burns on one end. The burning time at ground level is 10 seconds. The cartridge has “pop-out” drag fins to partially control the trajectory. This design may have been the first so-called aerodynamic flare decoy. The Universal Match Corporation, Saint Louis Missouri developed this flare. The RR-82 flare is assembled into the RR-82(XY-1)/ALE flare assembly, which has seventeen 11.5-inch tubes and 1 flare per tube.

RR-88 “Balls of Fire” Decoy Flare: This flare is compatible with the AN/ALE-14 dispenser and the AN/ALE-20 dispenser in the B-47 bomber and the B-52 bomber.

respectively. The carbon shell on the RR-88 flare contains a thermite composition consisting of 22.5% aluminum, 76.5% tungsten oxide and 1% Teflon®-7X. This design is also known as the Balls of Fire (BOF). The burning time at ground level is 30 seconds. The flares are assembled into the RR-88(XY-1)/ALE flare assembly, which has 2 tubes and 2 flares per tube. The Balls of Fire flare is discussed further in the section entitled Balls of Fire Decoy (BOF).

RR-88(XY-1)ALE Flare Assembly: This flare assembly is for the B-52 bomber. The dispenser concept contains two ejection tubes. Each tube has two BOF flares encapsulated with polyurethane foam in a metal capsule.

RR-96 Countermeasure Flare: This nomenclature has been applied to two different countermeasure flare configurations. One flare, 1.13 inches in diameter by 5.25 inches long, is used as a payload in a 2-stage SPAROAIR sounding rocket. Sixteen of these flares are fitted into the nose cone. Dr. Raison at the Armour Research Foundation of the Illinois Institute of Technology was the project engineer. The other flare is used in the nose of the ALE-9 forward launch chaff rocket system. The rocket is the XADR-9A countermeasures rocket developed by Tracor, Austin Texas.

RR-98 Decoy Flare: This flare is compatible with the AN/ALE-14 dispenser and the AN/ALE-20 dispenser in the B-47 bomber and the B-52 bomber respectively. The RR-98 flare, which is similar to the RITA-I flare, was developed for the RR-98(XY-1)/ALE flare assembly. The flare burns on all surfaces for 6 seconds at ground level. The grain is 1.88 inches in diameter by 5.75 inches long. The grain composition is 54% magnesium, 44% Teflon® and 2% nitrocellulose. The RR-98 flare is a joint development by Picatinny Arsenal and Lambert Engineering Company.

RR-98(XY-1)/ALE Flare Assembly: (Quick Response Capability QRC-87): This assembly, named Mfg. Model 103, has 17 tubes with two RITA-I flares per tube. The assembly is called a cartridge when the flares are loaded in the tube.

RR-98(XY-1)/ALE Flare Assembly-Variant: This assembly has six tubes with two flares per tube. A flare similar to the RITA-II flare was developed for the RR-98(XY-1)/ALE Flare Assembly-Variant. The flare burns on all surfaces for 6 seconds at ground level.

RR-108 Grain: This is the MTV flare grain for the ALA-17 flare.

RR-115 Flare: This is a 2-inch by 3-inch by 5-inch rectilinear flare manufactured by the Armour Research Foundation of the Illinois Institute of Technology. It fits the USAF 669A Phase I dispenser. All RR-115 flares contain pressed MTV compositions, an Epon case, a mechanical inertial igniter and a Pyrocore ignition train.

RR-115 Type I Flare: The RR-115 Type I flare is a composite of two low-density pellets in an Epon case, which remains intact during functioning. The Type I uses three consecutively burning compounds in the double-end burning epoxy inhibited pellet. The RR-115 Type 1 flare exhibits a rapid rise to a high intensity in 2 seconds which then levels to about 10 seconds burning time. The device weighs 1.34 pounds. The grain composition is 66% magnesium and 34% Teflon. The first fire slurry, in parts by weight, is 57.1 parts barium chromate, 25.8 parts aluminum, and 74.2 parts tungsten(VI) oxide.

RR-115 Type II Flare: The RR-115 Type II flare is nozzled and contains two high-density pellets and an Epon case, which remains intact during functioning. The Type II is double-end burning with a nozzle in each 2-inch by 3-inch face of the non-combustible case. The burning profile has a fast rise and then levels off to 6 seconds. The device weighs 1.34 pounds. The grain composition is 66% magnesium and 34% Teflon®. The first fire slurry, in parts by weight, is 57.1 parts barium chromate, 38.1 parts zirconium, and 4.8 parts nitrocellulose.

RR-115 Type III Flare: The RR-115 Type III flare has two low-density pellets, each of which has a large slit filled with first fire material in one of the 2 inch by 3 inch surfaces. It has an Epon case that burns away with the flare. The Type III is double-end burning with a slotted nozzle in each 2-inch by 3-inch face of the inhibited grain. It exhibits a high sharp radiation peak followed by uniform radiation for 4 seconds. The device weighs 1.34 pounds. The grain composition is 66% magnesium and 34% Teflon®. The first fire slurry, in parts by weight, is 57.1 parts barium chromate, 38.1 parts zirconium, and 4.8 parts nitrocellulose.

RR-119 Flare: Early variant: This is a 2-inch by 2-inch by 5-inch flare provided by Space Ordnance Systems. It fits the USAF 669A Phase-I dispenser. The composition is pressed to make the grain. Mentioned in a 1968 report.

RR-119 Flare: Later variant: This 2-inch thick by 3-inch wide by 5-inches long flare variant is dispensed from the AN/ALE-28 dispenser on an Air Force F-111 aircraft. The composition consists, in parts by weight, of 62 parts magnesium, 38 parts Teflon®, and 2 parts polyester binder. In the mid-1970s, the RR-119 flare was the highest performing flare in production. Mentioned in a 1973 report. The device weighs 2 pounds. It contains the Illinois Institute of Technology Research Institute developed inertial bore-safe igniter parts. The manufacturer is Celesco.

RR-138 Grain: This is the MTV flare grain for the ALA-34 flare.

QRC-127 (subset 10/ALQ-27) Flare Assembly: This assembly has six tubes with four flare cartridges per tube. A flare similar to the RITA-III was developed for this assembly by Aerojet-General Corp. of Azusa California.

QRC-127 Flare: This flare, similar to the RITA-III, was developed at the Aerojet-General Corp. for protection of the B-52 bomber. The flare grain is 2.1 inches long

by 2.6 inches in diameter. The flare is an end-burner, which burns for 7 seconds at ground level. The flare composition is 70% magnesium and 30% Teflon®. The pressed pellet grains are assembled into the aluminum case. Ignition is by electric squib. It is compatible with the AN/ALA-20 dispenser.

QRC-353 (T)-1 Flares: Unidynamics/Phoenix Division of Universal Match Corporation Industries developed these Air Force flares. Two flares were developed, the Type I and the Type II.

QRC-353 (T)-1 Type I Flare: The Type I flare is compatible with the M-112 photoflash cartridge and the Lambert LA-307A photoflash dispenser. The flare has the external configuration of the M-112 photoflash cartridge and incorporates a bore-safe igniter. The Type I differs mainly in size from the Type II. The M-112 cartridge dimensions are 1.57 inches in diameter by 7.73 inches long. The fully loaded device weight is 0.88 pounds. The grain dimensions are 1.45 inches in diameter by 3.80 inches long. The grain weighs 0.36 pounds and consists, in parts by weight, of 60 parts magnesium, 27.5 parts Halon (G80), 5 parts anthracene, and 7.5 parts Fluorel® (KF2140).

QRC-353 (T)-1 Type II Flare: The Type II flare is compatible with the M-123 photoflash cartridge and the Lambert LA-308A photoflash dispenser. The flare has the external configuration of the M-123 photoflash cartridge and incorporates a bore-safe igniter. The Type I differs mainly in size from the Type II. The Type II cartridge dimensions are 2.88 inches in diameter by 8.45 inches long. The fully loaded device weight is 3.22 pounds. The grain dimensions are 2.71 inches in diameter by 4.4 inches long. The grain weighs 1.22 pounds and consists, in parts by weight, of 60 parts magnesium, 27.5 parts Halon (G80), 5 parts anthracene, and 7.5 parts Fluorel® (KF2140).

TAU-15/B Infrared Target Flare: This is an Air Force expendable aerial target flare designed to provide an airborne infrared target for utilization in aircrew training and to checkout systems employing infrared seeking missiles. This flare was designed to provide target augmentation for the TDU-4/B, TDU-6/B, TDU-9/B, TDU-15/B, and TDU-17/B tow targets. The US Flare Division of the Atlantic Research Corporation produced the TAU-15/B infrared tracking flare, which is the Air Force tentative standard of the NOTS Model 711A flare. The TAU-15/B flare evolved into the Navy Mk 28 Mod 0 tracking flare.

This decoy has a grain in two different diameters. The diameter is 1.938 inches for about two-thirds of the base end and 1.750 inches diameter for about one-third of the ignition end. The flare is 9.5 inches long without the ignition connector and 10.375 inches with. The electrical ignition system consists of a bayonet connector, a Mk 2 Mod 0 squib and first-fire material. The squib is embedded in 5 grams of first-fire material at the front end of the flare. The order of ignition is squib, first-fire material, and then main illuminant. The main illuminant composition consists of 54% magnesium, 30% Teflon®, and 16% Kel-F® #40 wax.

The composition details as of 1958 are: The first fire material is 10% amorphous boron and 90% barium chromate. The main illuminant, pressed in five increments, is 54% magnesium gran 15, 30% Teflon® no. 1 (E. I. Dupont Chemical Company powder BD 500) and 16% Kel-F® wax (Kellog Chemical Corporation). This composition is based on the composition in the NOTS Model 702A flare and is also known as the NOTS Standard Composition.

The flare consists of a linen impregnated tube filled with pellets and first fire. The outside diameter is 1.94 inches. The unit weighs 1.58 pounds. After the metal sleeve is added, the flare case's outside diameter is 2 inches including the 6-inch long metal external sleeve by 10.250 inches long. The metal sleeve was added to prevent disintegration of the linen-Micarta flare casing. It increased the unit weight to 1.67 pounds. The added result is an increase in the radiant intensity in the 1.5μm to 2.7μm bandpass region with a decrease in burning time at altitude.

TAU-15 107E Flare: Ordnance Research Inc provided this unit in the form of a cast pyrotechnic flare to simulate the TAU-15 flare system. The units are in the form of a 6-inch long by 1.250-inch outside diameter cylinder containing a castable magnesium-fluorocarbon composition.

TAU-50 Flare and TAU-56/B Flare: See the comment in the description of the AGX0827 target flare about erroneous identification.

TAU-56/B Target Flare-Earlier Variant: Aerojet-General built this flare about 1963. It has an outer case diameter of 2.0 inches. The length of the outer steel shell is 12.5 inches. The flare composition weight is 1.5 pounds. The total device weight is 3.5 pounds. The nominal burning time is 90 seconds.

TAU-56/B Target Flare-Later Variant: A later variant built by Aerojet-General, which was put into production, had a nickel-plated steel outer casing diameter of 2.5 inches giving the flare composition 70% more burning area than the earlier variant. The overall flare length including the ogive nose is 15.1 inches. The unit weighs 4.7 pounds. This flare is intended for use on the Q-2C drone and the TDU-9/B tow target. The composition, in parts by weight, is 65 parts magnesium powder, 35 parts Teflon®, and 5 parts anthracene. Flares made after July 1963 contain 3 or 4 parts by weight anthracene.

TAU-56 105E Flare: Ordnance Research Inc provided this pyrotechnic cast flare to simulate the TAU-56 flare system. The units are in the form of a 6-inch long by 1.250- inch outside diameter cylinder containing a castable magnesium-fluorocarbon composition. The composition is similar to that in the W251 flare.

Tactical Fighter Attack Flare (TFAF): A model of the TFAF flare, about 3.1 inches long by 0.4 inches in diameter with four fins on the tail was used at the Arnold

Engineering Development Center, Arnold Air Force Station Tennessee to determine safe separation of the flare from an F-4C aircraft.

XADR-9 Countermeasure Flare: The XADR-9 forward launched countermeasure flare is the payload for the XADR-9A countermeasure rocket system. The Flare Northern Division of the Atlantic Research Corporation developed the flare for Tracor Inc., the prime contractor for the XADR-9 rocket. The payload also is identified as the RR-96 flare. The ADR-9A countermeasure rocket system is compatible with the AN/ALE-25 pod mounted dispenser on B52-H aircraft. The unit, including the chaff dispenser system, the flare and the rocket propulsion system is 74 inches long by 2.75 inches in diameter. The flare grain composition, in parts by weight, is 39.1 parts 1H,1H,7H dodecafluoro-1-heptylmethacrylate, 47 parts magnesium, 1 part bis-phenyl-A-dimethylacrylate, 2 parts aluminum staples, and 4 parts anthracene. The grain is 16 inches long by 2.125 inches in diameter and weighs 5.2 pounds. This flare is unique in configuration, consisting of an internal-burning cast grain with a six-gear tooth axial channel. The internal burning performance provides the infrared signal without weakening the walls of the entire structure during the 12-second life of the countermeasure system.

RITA and FLORA Flares: The so-called RITA and FLORA flares make up a family of flares developed by Picatinny Arsenal for the Air Force for protection of the B-52 bomber. Their contents evolved from an illuminating composition for visible output to a composition that radiates in the infrared. The RITA-FLORA developmental evolutions lead to the development of the ALA-17 MTV flare.

RITA Flare: The generic RITA flare has a composition for light production that is 66.7% magnesium, 28.5% sodium nitrate, and 4.8% binder.

RITA Flare 3-second variant: The RITA flare 3-second variant is 1.75 inches in diameter by 1.75 inches long. The illuminating composition consists of 47.6% magnesium (22µm particle size), 47.6% sodium nitrate and 4.8% Laminac® binder. Picatinny Arsenal fabricated this flare. Mentioned in 1956 report.

RITA Flare 5-second variant: The RITA flare 5-second variant is 1.75 inches in diameter by 1.75 inches long. The illuminating composition consists of 23.8% magnesium (gran 17), 23.8% magnesium (22µm particle size), 47.6% sodium nitrate and 4.8% Laminac® binder. Picatinny Arsenal fabricated this flare. Mentioned in 1956 report.

RITA Flare Jacketed variant: The RITA flare jacketed variant is fabricated with the same formulation and dimensions as the 5-second variant RITA flare. It is pressed into a steel wire mesh screen in the form of a cylindrical sleeve extending over the complete wall area. Both ends of the flare are uncovered. The overall length is 2-inches. Picatinny Arsenal fabricated this flare. Mentioned in 1956 report. This design may be related to the perforated-can flare design.

RITA-I Flare: The RITA-I flare is 1.875 inches in diameter by 5.75 inches long. It contains a composition of 54% magnesium, 44% Teflon® and 2% nitrocellulose. The flare burns on all surfaces for 11 seconds at ground level. Picatinny Arsenal developed the RITA-1 flare.

RITA-II Flare: The RITA-II flare is 2.25 inches in diameter by 5.75 inches long. It is identical to the RR-98/ALE Decoy Flare except in size. It contains a composition of 54% magnesium, 44% Teflon® and 2% nitrocellulose. The flare burns on all surfaces for 6 seconds at ground level. The RITA-II flare was developed for the AN/ALE-14 dispenser and the AN/ALE-20 dispenser systems for B-47 and B-52 bombers respectively. Picatinny Arsenal developed the RITA-II flare. The RITA-II flare is regarded as the precursor of the ALA-17 flare.

RITA-III Flare: The RITA-III flare is 2.59 inches in diameter by 2.1 inches long. It contains an infrared composition of 70% magnesium and 30% Teflon®. Another reference gives the dimensions as 5 inches long by 1.750-inches in diameter. Picatinny Arsenal developed the RITA-III flare.

FLORA Flare: The FLORA flare started with a RITA flare that initially contained 66.7% magnesium, 28.5% sodium nitrate and 4.8% binder composition. That composition radiates in the visible. Later it was loaded with a mixture of 54% 22-µm mesh magnesium and 46% Teflon®-7X to provide infrared radiation. The FLORA flare grain is cylindrical, weighs about 1545 grams, and occupies 54.75 cubic inches. The grain has an 80.22 square inch surface area. Burning takes place simultaneously over the entire surface.

FLORA Type B Flare: The composition in the FLORA Type B flare consists of 42% magnesium, 49.2% Teflon® and 8.8% of a boron-barium chromate mixture. The latter mixture consists of 16% boron and 84% barium chromate. The FLORA Type B flare grain is cylindrical, weighs about 1545 grams, and occupies 54.75 cubic inches. The grain has an 80.22 square inch surface area. Burning takes place simultaneously over the entire surface.

FLORA Type C Flare: The composition in the FLORA Type C flare consists of 39.9% magnesium, 46.8% Teflon® and of a 13.3% boron-barium chromate mixture. The latter mixture consists of 16% boron and 84% barium chromate. The FLORA Type C flare grain is cylindrical, weighs about 1545 grams, and occupies 54.75 cubic inches. The grain has an 80.22 square inch surface area. Burning takes place simultaneously over the entire surface.

Flares Assigned a Mk and Mod

Mk 3 Mod 0 Target Flare: The Mk 3 Mod 0 target flare is also known as the BB-9 flare. It has a burning time of 30 seconds. The manufacturer is the Hughes Aircraft Company. It is electrically ignited with dimensions of 2.25 inches in diameter by a little over 8 inches long. The BB-9 has a very high airborne output that varies considerably during burning.

Mk 21 Mod 0 Tracking Flare The illuminating composition in the Mk 21 Mod 0 tracking flare is 54% magnesium, 34% sodium nitrate, and 12% Laminac®, a polyester binder. It is packaged in the Mk 26 Mod 0 target rocket kit. This tracking flare is intended to ignite parasitically from thrust gases of the propulsion unit in environments up to Mach 1.5 and acceleration forces up to 80 G's. The burning duration is 15 seconds at an intensity of 100,000 candela (visible) and about 50 W/sr in the infrared. The 1-inch diameter by 10 inches long case is aluminum. It has marginal ignition above 35,000 feet altitude. The developmental precursor of the Mk 21 Mod 0 flare is the NOTS Model 701A.

Mk 23 Mod 0 Guided Missile Flare: The Mk 23 Mod 0 guided missile flare is also known as an electric tracking flare for the Bullpup missile. Its purpose is to permit tracking of missile trajectories. It is 10 inches long by 1.75 inches in diameter and contains about 0.28 pounds (126 grams) of pyrotechnic components. The NOTS Model 714A flare replaced the Mk 23 Mod 0 flare.

Mk 25 Mod 0 Tracking Flare: The Mk 25 Mod 0 flare is used to track the Talos missile. It has a 0.125-inch thick cotton-based phenolic body.

Mk 26 Mod 0 Target Rocket Kit: The Mk 26 Mod 0 kit contains the Mk 21 Mod 0 tracking flare.

Mk 27 Mod 0 Guided Missile Flare: The Mk 27 Mod 0 flare underwent Prototype Production for Evaluation at NAD Crane in the early 1960s. It evolved from the NOTS Model 714A tracking flare for the Bullpup missile. This version burns about 40 seconds with visible intensity of 100,000 candela in the first 2-8 seconds and 140,000 candela thereafter.

Mk 28 Mod 0 Tracking Flare: The Mk 28 Mod 0 flare evolved from the NOTS Model 711A flare alternatively known by the Air Force as the TAU-15/B flare. The infrared grain composition in the Mk 28 Mod 0 flare consists of 54% magnesium, 30% Teflon® and 16 % Kel-F® #40 wax to which 3 to 5 parts by weight of graphite is added to facilitate consolidation of the composition. The grain is 1.44 inches in diameter by 9.5 inches long. The flare is used to track tow targets.

Mk 28 Mod 1 Tracking Flare: The infrared grain composition in the Mk 28 Mod 1 flare consists of 54% magnesium, 30% Teflon® and 16 % Kel-F® wax to which 3

parts by weight graphite is added to facilitate consolidation of the composition. The ignition composition is a mixture of 90% barium chromate and 10% boron powder.

Mk 28 Mod 2 Tracking Flare: The Mk 28 Mod 2 flare evolved from the Mk 28 Mod 1 tracking flare. The Mk 28 Mod 2 flare also uses Kel-F® wax as a binder. Because there were problems with the Kel-F® wax, a new formula was developed. The flare with the new formula with Viton® A became the Mk 28 Mod 3 Tracking Flare.

Mk 28 Mod 3 Tracking Flare: The Mk 28 Mod 3 flare evolved from the Mk 28 Mod 2 tracking flare. It is used as a target for infrared seeking missiles. It burns for about 48 seconds when deployed at 40,000 feet at 0.7 Mach. The infrared composition in the grain of the Mk 28 Mod 3 flare is 60 parts magnesium powder, 40 parts Teflon® and 5 parts Viton® A by weight. The ignition composition is a mixture of 90% barium chromate and 10% boron powder. In 1963, Mr. Leonard B. Arnold conducted the Prototype Production for Evaluation (PPE) of this flare at NAD Crane. The favorable performance during PPE qualified the unit for release to production.

Mk 33 Mod 0 Tracking Flare: The Mk 33 Mod 0 flare was designed for visually tracking the Sidewinder 1A and 1C missiles. It also is added to Mk 26 Mod 0 target rocket kits where it is used for Sidewinder 1A target augmentation. The forerunner of the Mk 33 Mod 0 flare is the NOTS Model 702B flare. The Mk 33 Mod 0 flare is 1-inch in diameter by 10 inches long. The grain composition contains 54% magnesium gran 15, 30% Teflon® no. 1, and 16% Kel-F® wax no. 40. Whereas the grain composition formula is typical of an infrared composition, one should not overlook that the burning composition also radiates a large amount of light. Ignition problems were noted during tests due to slipstream damage to the flares. NOTS forwarded the Mk 33 Mod 0 flare documentation package to the Navy Headquarters on 19 January 1962.

Mk 33 Mod 1 Tracking Flare: To overcome the Mk 33 Mod 0 flare ignition problems, 8-evenly spaced 0.1875-inch holes replaced the parasitic slots to insure positive ignition of the Mk 33 Mod 1 flare. This resulted in assignment of Mk 33 Mod 1 tracking flare as the new designation replacing the Mk 33 Mod 0 flare. Burning takes place simultaneously over the entire surface. The grain of the MK 33 Mod 1 tracking flare consists of 54% magnesium gran 16, 30% Teflon® no. 1, and 16% Viton® A. This is a NOTS development.

Mk 37 Mod 0 Infrared Target Flare: The Mk 37 Mod 0 is the target flare developed by Special Devices, Incorporated for the Teledyne Ryan BQM-34 drone, one of the first jet-propelled targets, which later became known as the Firebee. Two flares are carried on each wing tip and are ignited individually on command. The Mk 37 Mod 0 flare is 21.6 inches long by 3 inches in diameter. The grain is prepared by an incremental pressing technique. The grain composition consists, in parts by weight, of 46.5 parts magnesium, 13.6 parts aluminum, 38.1 parts Teflon® and 1.8 parts Vistanex™ solids. The ignition composition consists of a mixture of 10% boron and

90% barium chromate. The first fire consists of a mixture of magnesium, Teflon®, boron, polyisobutylene and barium chromate. Earlier, Special Devices Incorporated developed the 5B1.5.1-1 flare, the forerunner of the Mk 37 Mod 0 flare. The Special Devices 5B1.5.1-1 infrared flare and the Mk 37 Mod 0 flare later were both found to be unsatisfactory. The Targets Office at the Naval Missile Center, Point Mugu, California reported ignition failures with the Mk 37 Mod 0 flare, and also that it burned holes in the motor when tested at 3,000 feet altitude on the Beech AQM-37A small supersonic air-launched expendable target drone. In September 1963, the KD2B-1 drone production version became operational with the U. S. Navy. Shortly before, in June 1963, the KD2B-1 drone was redesignated as the AQM-37A drone.

EX 42 Mod 0 Decoy Flare: This flare was developed for use in Lundy AN/ALE-33 chaff dispensers. The EX 42 Mod 0 flare and the EX 43 Mod 0 flare are similar in that they essentially are flat slabs of grain material expelled from dispensers at a comparatively low velocity. The pyrotechnic pellet is in the shape of a rectangular block, which is totally encased in a plastic outer cover. It is about 4.9 inches long by 2.90 inches wide by 0.875 inches thick. There are about 0.43 pounds (196 grams) of energetic materials in this device.

Mk 42 Mod 0 Decoy Flare: This flare was developed for Lundy chaff/flare dispensers. It is derived from the NOTS Model 733 series flare. The flare format, similar to the RR-72 flare cartridge, is extruded in a rectilinear shape 4.875 inches long by 3 inches wide by 1.031 inches thick. Specifications include a release velocity of Mach 0.9, a functioning range of up to 70,000 feet altitude and a burning time of at least 2 seconds at 50,000 feet. The Mk 42 Mod 0 flare was adapted to the Lundy AN/ALE-33 chaff dispenser.

EX 43 Mod 0 Decoy Flare: This flare was developed for use in AN/ALE-18 chaff dispensers. The EX 42 Mod 0 flare and the EX 43 Mod 0 flare are similar in that they essentially are flat slabs of grain material expelled from dispensers at a comparatively low velocity. The wedge-shaped pyrotechnic pellet is totally encased in a plastic outer cover. There are about 0.54 pounds (243 grams) of energetic materials in this device.

MK 43 Mod 0 Decoy Flare: This flare is derived from the NOTS Model 715 flare. It is an extruded wedge configuration with 24 units fitting into the AN/ALE-18 pneumatic chaff dispenser. The grain consists of 54% magnesium, 30% Teflon® and 16% Viton® A. The grain shape is 3.6 inches wide by 2.73 inches long by 1.06 inches thick. The thickness dimension tapers to 0.34 inches.

EX 46 Mod 0 Decoy Flare: As reported by Dr. Handler and Mr. J. W. Hanzel of China Lake in 1967, they started work on the development of the EX 46 Mod 0 flare in June 1966. The predecessor to the EX 46 Mod 0 flare is the NOTS Model 400A decoy flare. The NOTS Model 400A flare's composition consists of 55% magnesium, 30% Teflon®, and 15% Viton® A. Pyrotechnicians at NOTS were

requested to develop this flare as a backup to a similar flare being developed by Unidynamics/Phoenix Division Arizona. Ignition is by a pull wire igniter. The ignition strip is made from composition PL 6239. The original grain consists of composition PL 6239. Based on flight test information, the grain composition was changed from composition PL 6239 to composition PL 6328 to obtain a shorter rise time and greater average output. During a second flight test, they evaluated composition PL 6920, a very high-output short-burning composition. Initial performance data were favorable. The device weight is about 0.53 pounds (240 grams). The diameter is 1.4 inches and the overall length is 5.875 inches. The EX 46 Mod 0 decoy flare was developed for the AN/ALE-29 chaff dispenser. That dispenser requires a cylindrical package to be expelled at a relatively high velocity. The design for the EX 46 Mod 0 decoy flare was frozen in December 1966.

Mk 46 Mod 0 Decoy Flare: NOTS investigators reported that work started in mid-1966 on the development of the EX 46 Mod 0 decoy flare, which evolved into the Mk 46 Mod 0 decoy flare. The design is derived from the NOTS Model 400A flare. The Mk 46 Mod 0 decoy flare was released to limited production in December 1967. Its purpose is to protect A-3, A-4, A-6, A-7, F-4 and F-8 aircraft against the AA-2 Atoll air-to-air missile threat. These aircraft have the AN/ALE-29 chaff-flare dispenser installed.

The flare is 1.43 inches in diameter by 5.81 inches long and has a flare grain weight of 0.36 pounds (165 grams). The MTV formulation selected for the grain is composition PL 6239. The Mk 46 Mod 0 flare is initiated with a pull wire igniter and has a cross hole though the grain near the center. The ignition process propagates by the flame from the pull wire through the cross hole to ignite the ribbon of igniter material, which in turn ignites the grain. The grain is made by the extrusion process. The flare has a longitudinal flat spot extruded on the circumference of the grain. A ribbon of igniter material is stapled onto the flat spot. In this configuration, the grain is assembled into the case. The grain is not wrapped with aluminum foil tape. The inside diameter of the flare case is reduced at a point about 0.375 inches from the closure disk to form a positive stop. The stop prevents the ignition end parts from exiting the case. At the stop, the momentum of the grain pulls the pull wire igniter to start the ignition process.

The Air Test and Evaluation Squadron Four (VX-4) at Point Mugu California evaluated the Mk 46 Mod 0 flares for effectiveness. VX-4 used the Sidewinder AIM-9B missile as a surrogate for the Atoll threat missile. The device is compatible with the AN/ALE-29A dispenser, the AN/ALE-37A dispenser, and the AN/ALE-39 dispenser. Dr. Handler of China Lake reports that the Mk 46 Mod 0 flare replaced the Mk 47 Mod 0 flare and that the Mk 46 Mod 0 flare does not have a fast enough rise to peak intensity to protect against advanced missiles. This is a NOTS development. NAD Crane manufactured the flare.

Mk 46 Mod 1 Decoy Flare: The improved version of the Mk 46 Mod 0 flare became the Mk 46 Mod 1 flare. It was improved for high altitude use and had a faster rise

time to peak intensity. The flare is 1.43 inches in diameter by 5.81 inches long. The Mk 46 Mod 1 flare is initiated with a pull wire igniter and has a cross hole through the grain near the center. The ignition process propagates by the flame from the pull wire igniter through the cross hole to ignite the ribbon of igniter material, which in turn ignites the grain. The grain is made by the extrusion process. The flare has a longitudinal flat spot extruded on the circumference of the grain. A ribbon of igniter material is stapled onto the flat spot. In this configuration, the grain is assembled into the case. The grain is not wrapped with aluminum foil tape. The inside diameter of the flare case is reduced at a point about 0.375 inches from the closure disk to form a positive stop. The stop prevents the ignition end parts from exiting the case. At the stop, the momentum of the grain pulls the pull wire igniter to start the ignition process. NOTS developed this improvement. NAD Crane manufactured the flare.

Mk 46 Mod 1A Decoy Flare: This Navy MTV flare is 1.43 inches diameter by 5.81 inches long. The flare is initiated with a pull wire igniter and has a cross hole through the grain near the center. The ignition process propagates by the flame from the pull wire igniter through the cross hole to ignite the ignition slurry, which in turn ignites the grain. The grain is made by the extrusion process. There are 10 longitudinal grooves extruded onto the grain circumference, which are filled with ignition slurry. The grain in this flare is wrapped with aluminum foil tape. For the Mk 46 Mod 1A, the inside diameter of the flare case is reduced at a point about 0.375 inches from the closure disk to form a positive stop. The stop prevents the ignition end parts from exiting the case. At the stop, the momentum of the grain pulls the pull wire igniter to start the ignition process. The Mk 46 Mod 1A flare has a multi-piece cartridge retainer assembled inside the case at the ignition end. Mentioned in a 1977 report.

Mk 46 Mod 1B Decoy Flare: The MTV composition formulation in this variant was modified to provide faster burning, which in turn results in a much higher radiant intensity. The grain has 12 longitudinal grooves on the grain surface, maybe the first to incorporate such a design. The 12 grooves in comparison to the 10 grooves of the MK 46 Mod 1C flare provided extra burning surface. The grooves are filled with ignition slurry. The grooves are formed during the extrusion process. The grain in this flare is wrapped with aluminum foil tape. Other design features are similar to those in the Mk 46 Mod 1A flare. The Mk 46 Mod 1B flare later was redesignated the MJU-8/B decoy flare. This flare is 1.43 inches diameter by 5.81 inches long.

Mk 46 Mod 1C Decoy Flare: This Navy MTV flare is 1.43 inches diameter by 5.81 inches long. The flare is initiated with a pull wire igniter and has a cross hole through the grain near the center. The ignition process propagates by the flame from the pull wire igniter through the cross hole to ignite the ignition slurry, which in turn ignites the grain. The grain is made by the extrusion process. There are 10 longitudinal grooves extruded onto the grain circumference, which are filled with ignition slurry. The grain in this flare is wrapped with aluminum foil tape. For the Mk 46 Mod 1C, the inside diameter of the flare case is reduced at a point about 0.375 inches from the closure disk to form a positive stop. The stop prevents the ignition

end parts from exiting the case. At the stop, the momentum of the grain pulls the pull wire igniter to start the ignition process. The Mk 46 Mod 1C flare has a one-piece cartridge retainer assembled inside the case at the ignition end, which is an improvement over the multi-piece cartridge retainer in the Mk 46 Mod 1A.

Mk 47 Mod 0 Decoy Flare: The MK 47 Mod 0 flare was developed and manufactured by Unidynamics Division of Universal Match Corporation Industries. This flare is described in specification MIL-F-81545 Flare, Decoy. It is 1.43 inches in diameter by 5.81 inches long with a flare grain weight of 0.23 pounds (105 grams). The composition is pressed to make the grain. This flare was actually the first decoy flare designed for use in the AN/ALE-29 dispenser. It entered production in 1968. After the Illinois Institute of Technology Research Institute developed inertial bore-safe igniter parts and the grain are ejected, the safing hardware ignites the grain at the rear. The AN/ALE-29A dispenser has 30 tubes into which the flares are loaded. Dr. Handler of China Lake reports that the Mk 46 Mod 0 flare replaced the Mk 47 Mod 0 flare.

Mk 48 Mod 0 Decoy Flare: This is a NWC China Lake developed flare intended for ship protection. It is also known as the Ships Ordnance Infrared Decoy (SOID). In July 1968, China Lake was requested to develop this flare when it appeared the Army 33-18 flare development would not be available on schedule. The decoy grain is a magnesium/Teflon®/Viton® A rod extruded 1 inch in diameter by 12 inches long. The grain composition consists of a variation of composition PL 6328. This grain is assembled into a Mk 25 Marine Marker aluminum canister, which is about 18 inches long by 3 inches in diameter. The Mk 48 Mod 0 flare is initiated by the introduction of seawater to the interior of the base assembly. The ignition system consists of a Mk 72 seawater activated battery, which is mounted within the base assembly, and a Mk 1 squib fitted in the forward end of the flare grain. It was released to production in 1971. The Mk 48 Mod 0 flare can only be launched by hand. NAD Crane manufactured the flare.

Mk 48 Mod 1 Decoy Flare: The Mk 48 Mod 1 decoy flare is similar to the Mk 48 Mod 0 flare. It differs in that it can be launched either by hand or from the Mk 133 Mod 0 flare launcher system.

EX-49 Mod 0 Decoy Flare: This is the forerunner of the Mk 49 Mod 0 flare. The grain burns internally and externally. Initially the grain had a twelve-star shaped perforation longitudinally in the grain center. In early 1971, the design with 12-longitudinal holes around the circumference was chosen in place of the star shaped perforation. The 12-hole configuration was designated the EX 49 Mod 0 flare. Mentioned in a 1971 report. Developed by NWC, China Lake.

Mk 49 Mod 0 Decoy Flare: This flare has a new bore safe system and is 1.42 inches in diameter by 5.80 inches long. The grain is 1.33 inches in diameter by 4.87 inches long. The flare grain weighs 0.34 pounds. The flare mixture is composition PL 9000. The Mk 49 Mod 0 decoy flare was first mentioned in a June 1973 report.

Mr. Daniel L. Harp, Mr. Kenneth L. Foote, and Mr. Allen of China Lake reported details of this flare in early 1974. This flare is also known as the "spaghetti" flare. The grain has twelve 0.125-inch longitudinal holes around the circumference of the grain very close to the outside perimeter. An extruded ignition cord composed of magnesium-Teflon® composition PL 6239 mixture, called spaghetti, is lased continuously through all the holes. This Mk 49 Mod 0 flare design is a successor to the Mk 46 Mod 0 flare and is the forerunner to the MJU-8A/B decoy flare by way of the MJU-16/B flare, the MJU-21(XCA-1)/B flare and the MJU-8/B PIP flare. Sometimes graphite is added to the composition to improve the grain extrusion properties. Graphite also is supposed to improve the burning rate and long wavelength properties. Naphthalene and anthracene also were explored to improve long wavelength properties. A spaghetti flare grain is configured such that the extrusion process is the only way to produce it. The Mk 49 Mod 0 was not released to production.

EX 50 Mod 0 Decoy Flare: This MTV flare is about 1972 vintage and is the forerunner to the Mk 50 Mod 0 flare. The case features are 1.57 inches in diameter by 3.85 inches long with a weight of 0.43 pounds. The grain features are 1.4 inches in diameter by 2.4 inches long with a weight of 0.22 pounds. The EX 50 Mod 0 pyrotechnic grain is N-35 propellant. The EX 50 Mod 0 has a much faster burning rate than the Mk 50 Mod 0 flare.

Mk 50 Mod 0 Decoy Flare: This flare is a quick response development designed to be compatible with the AN-M8 pyrotechnic pistol, from which the decoy flare is fired. The unit consists of a 1.57-inch diameter by 3.85-inch long aluminum case that has a rimmed base to fit the pistol ejector. The extruded MTV grain is 1.4 inches in diameter by 2.4 inches long. It contains approximately 0.22 pounds (100 grams) of flare grain, which is coated internally on each end with 0.70 grams of ignition charge mixture. The propelling charge is 2.5 grams black powder. An M39A1 percussion primer is located in the base end. The Mk 50 Mod 0 decoy flare is identical to the EX 50 Mod 0 flare, with one minor exception. The magnesium powder used in the Mk 50 Mod 0 flare could not meet the specification for use in N-35 propellant. Mk 50 Mod 0 flare grains are extruded from composition PL 9001, which is similar to N-35 in formulation but allows the use of a wider magnesium particle size range. Development of the Mk 50 Mod 0 decoy flare by NWC China Lake was completed in 1972. Unlimited production was authorized in 1973. The Naval Ordnance Station Indian Head Maryland produced this flare. The MTV Army XM-197 flare is similar to the Mk 50 Mod 0 flare.

EX 51 Mod 0 Decoy Flare: The EX 51 Mod 0 flare development, started in 1972. It is an effort to get increased infrared radiant intensity for greater effectiveness and wider use knowing that the Mk 50 Mod 0 is deficient in that regard. The grain in the Mk 50 Mod 0 flare is made of N-35 propellant, which is intended primarily for use as a propellant and gives less infrared emission that those formulations intended for pyrotechnic use. It also is limited in combustion at high altitude. The intent is to replace the N-35 propellant in the Mk 50 Mod 0 flare with a composition that has a

greater infrared output and better functioning at altitude. The replacement formulation is composition PL 9000, which is composition PL 6920; 70% magnesium, 14% Teflon® and 16% Viton® A, with 10% graphite added. The composition ignites reliably with CT-144 ignition mix. The EX 51 Mod 0 flare is designed to be compatible with the AN-M8 pyrotechnic pistol, which is used to launch this decoy flare. The development was put on hold awaiting a request from Navy Headquarters that the item be produced or for an operational requirement. There is no record that the hold was removed from this development.

Flares Assigned an MJU Designation

MJU-2/B Aircraft Decoy Flare: NAD Crane engineers developed the MJU-2/B flare. The flare is 7.625 long by 1.568 inches in diameter. It contains 0.47 pounds (215 grams) of MTV composition and is ejected at 40 feet/second. The grain exterior is grooved to get additional surface area. Magnesium-Teflon® tubing is placed into the grooves to provide high initial radiant output. The flare exhibits a 300-millisecond rise time and a 3.2 second ambient burning time. At 40,000 feet altitude and 650 feet per second airspeed, it burns about 4.5 seconds. The flare is dispensed from the A6 or 9A Lambert photoflash ejector or a SUU-53A cartridge dispenser. The latter dispenser typically is used to discharge Weather Modification Units (WMU) catalyst generators units. WMU units are used for cloud seeding in an effort to facilitate rainmaking. Mr. Harold L. Benham and Mr. Orville L. Beckes NAD Crane reported this flare in 1974.

MJU-2A/B Aircraft Decoy Flare: This flare is an improved version of the MJU-2/B flare. The improvement is mainly in the ignition system. The extruded MTV grain exterior is grooved to get additional surface area. This flare dates to 1988.

MJU-3/B Countermeasures Flare: This flare and its dispenser are too large except for logistics aircraft. The flare also needs a reduced delay time. Mentioned in a 1972 report.

MJU-7/B Aircraft Decoy Flare: Prior to 1989 there only was one flare called the MJU-7/B flare, but it had 2 variants, which are not distinguished by a change in nomenclature. All variants are made with MTV to the same performance specification. The flare dimensions are 1 inch by 2 inches by 8 inches. The MJU-7/B flares are compatible with the Tracor AN/ALE 40 dispenser.

MJU-7/B Aircraft Decoy Flare variant 1: Before 1997, this variant of the MJU-7B flare was made with a pressed MTV grain and with a slider/interrupter/sequencer. The flare dimensions are 1 inch by 2 inches by 8 inches.

MJU-7/B Aircraft Decoy Flare variant 2: Before 1989, this variant of the MJU-7/B flare was made with an extruded MTV grain and was ignited parasitically. It does not have a slider/interrupter/sequencer. The flare dimensions are 1 inch by 2 inches by 8 inches.

MJU-7A/B Aircraft Decoy Flare: Starting in 1997 the Air Force had some flares made with an extruded MTV grain as in the MJU-7/B variant 2 flare and with a slider/interrupter/sequencer as in the MJU-7/B variant 1 flare. The designation given to these flares with an extruded MTV grain and with a slider/interrupter/sequencer is the MJU-7A/B flare. At this time, the manufacturing specification for the MJU-7A/B flare was changed to give the producer the option to choose which version (pressed or extruded grain) to make. The performance requirements stayed the same for the MJU-7A/B flare whether the grain is made by pressing or by extrusion. There was

no effort to change the nomenclature to indicate whether the flare contained a pressed grain or an extruded grain. This later made it difficult to identify the type of grain contained in an MJU-7A/B flare. The flare dimensions are 1 inch by 2 inches by 8 inches.

MJU-8/B Aircraft Decoy Flare: The MJU-8/B flare is formulated using extruded MTV to protect aircraft that radiate a large infrared signature. It is the counterpart to the Mk 46 Mods flare series that are formulated to protect aircraft that radiate a low infrared signature. The MTV composition formulation and grain configuration in this variant were modified to provide faster burning, which in turn results in a much higher radiant intensity. The grain has 12 longitudinal grooves on the grain surface, maybe the first to incorporate such a design. The 12 grooves in comparison to the 10 grooves of the MK 46 Mod 1C flare provided extra burning surface. The grooves are formed during the extrusion process. The grooves are filled with ignition slurry. The grain in this flare is wrapped with aluminum foil tape. Other design features are similar to those in the Mk 46 Mod 1C flare. The Mk 46 Mod 1B was redesignated the MJU-8/B decoy flare. This flare is 1.43 inches diameter by 5.81 inches long.

MJU-8/B PIP Aircraft Decoy Flare: This MTV extruded flare evolved into the MJU-8A/B decoy flare and is 1.43 inches in diameter by 5.81 inches long. The forerunner of this flare is the MJU-21(XCA-1)/B flare. The concept of longitudinal holes and the spaghetti igniter material continues in this variant.

MJU-8A/B Aircraft Decoy Flare: The forerunner of this MTV extruded flare is the MJU-8/B PIP. The MJU-8A/B flare is 1.43 inches in diameter by 5.81 inches long. This flare also utilizes the “spaghetti” flare design. The grain has twelve 0.125-inch longitudinal holes around the circumference of the grain very close to the outside perimeter. An extruded ignition cord composed of magnesium-Teflon® PL 6239 mixture, called spaghetti, is lased continuously through all the holes. This variant dates from 1986.

MJU-10/B Aircraft Decoy Flare: The MJU-10/B flare is a 2 inch by 2.5 inch by 8 inch MTV decoy flare primarily used on an Air Force aircraft.

MJU-16/B Aircraft Decoy Flare: The MJU-16/B flare is 1.43 inches in diameter by 5.81 inches long. It served as the test bed for a number of improvement concepts. This MTV flare also has the longitudinal holes around the grain circumference very near to the surface. It is into these holes that the spaghetti igniter material is laced. This design never was placed into production. The MJU-16/B flare improvements evolved into the MJU-21(XCA-1)/B flare.

MJU-21(XCA-1) Aircraft Decoy Flare: This MTV extruded flare is 1.43 inches in diameter by 5.81 inches long. It evolved from MJU-16/B flare developments into the MJU-8/B PIP decoy flare. The MJU-21(XCA-1) flare continued the spaghetti flare concept but in this instance, the longitudinal holes are relieved to the outside by a

small slot. This is done to regulate the ignition rate. Igniter material in the form of spaghetti is laced into these holes as in prior models. This variant dates to 1985.

MJU-22/B Aircraft Decoy Flare: This MTV extruded flare is 1.43 inches in diameter by 10.55 inches long. It might be considered the “long” version of the MJU-8A/B flare. It also contains the spaghetti flare concept and associated design. The extra length design allows one to dispense a flare with more radiative output from a single hole of the dispenser. This variant dates from 1991.

MJU-32/B Aircraft Decoy Flare: This MTV extruded flare is an improvement of the MJU-8A/B flare. It also is 1.43 inches in diameter by 5.81 inches long. The lacing of the spaghetti into the longitudinal holes of the grain is a very labor-intensive procedure. To reduce the labor cost, the holes were changed into a “T” shaped slot. Spaghetti no longer is required in this design. The concept of the “T” slot is that it would undergo fissure burning and there would no longer be a need for an igniter material in the slot. After many experiments with the shape of the slot, the final “T” shaped slot was chosen as the optimum balance between ignition speed and performance. Mr. Jeff Mulinix of NSWC Crane is the inventor of the “T” slot. This flare dates from 1995.

Flares with Commercial Designations

E216 Tracking Flare (Ejectable): This is a double-end burning ejected flare made by the Atlantic Research Corporation. The E216 flare is identical to the W216 flare. The MTV grain is 1.625 inches in diameter by 3 inches long and weighs 0.22 pounds. The composition is EW-50. The materials and proportions are unspecified.

W111B Tracking Flare: This is a commercial item made by the US Flare Corporation (USFC). It is 1 inch in diameter by about 10.125 inches long. It is electrically ignited and weighs about 0.75 pounds. The USFC W111B flare is interchangeable with the NOTS Model 702A flare.

W112B Infrared Augmentation Device: This device is for the modified 5-inch HVAR rocket powered TDU-11B target. It was designed to replace the Mk 21 Mod 0 flare. The first article was tested during 1963 at the Air Proving Ground Center, Eglin Air Force Base Florida to get data about performance at sea level and 22,000 feet altitude. The burning time at altitude is 70 seconds at 240 knots indicated air speed (KIAS). The flare is reliable over the minus 65 °C to +30 °C temperature regime. US Flare Division of the Atlantic Research Corporation manufactured the flare. The composition consists of 54% magnesium, 30% Teflon®, and 16% Kel-F® wax. The grain is pressed in increments into an aluminum case, which is thin walled and is consumed during burning. Since it is mounted on the target, the case burns in place and is not ejected. The front end has the ignition mixture exposed through vents to facilitate parasitic ignition by the rocket flame. The aluminum case is 6.5 inches long by 0.94 inches in diameter. The unit weighs about 0.5 pounds.

W114B Tracking Flare: This commercial flare is intended for use on the AGM-45A Shrike missile to obtain missile trajectory. Because of problems with this unit, the NOTS Model 743A flare and NOTS Model 743B flare were tried instead of the W114B flare.

W137 Tracking Flare: This flare was developed by US Flare Division of the Atlantic Research Corporation and was designed primarily for use with the Pogo-Hi rocket. The unit is 1.375 inches in diameter by 9 inches long and weighs about 1 pound. The grain weighs about 0.33 pounds. The unit burns for 40 seconds at sea level with an intensity of 450 W/sr in the 1.8μm to 2.7μm bandpass region. The W137 flare is ignited with one USF Model 706 Squib. The actual burning time is 120 seconds when mounted on the Pogo-Hi rocket during the time it is rising from ground launch to 68,000 feet and then free-falling back to the ground. The W137 flare is one of the earliest magnesium-Teflon® formulated flares. It dates to before October 1959.

W138 Tracking Flare: This flare is identical to the W137 flare but burns for 20 seconds at sea level and for 60 seconds in flight.

W204 Infrared Flare: US Flare Division of the Atlantic Research Corporation made the flare, which is in a 2-inch diameter by 10-inch long case. The W204 flare and the W205 flare differ in case material.

W205 Infrared Flare: US Flare Division of the Atlantic Research Corporation made the flare, which is in a 2-inch diameter by 10-inch long case. The W204 flare and the W205 flare differ in case material.

W205 Lot 1 Target Flare: This flare, manufactured by the Atlantic Research Corporation, is used on the TDU-4/B Tow Target. The flare is not ejected, but burns where it is mounted. An electrical connector at the rear end is used to ignite an electric agent embedded in the first fire at the front end. Ignition is by electric squib. The grain is in a stepped aluminum case that is wider at the front end. A layer of fiberglass insulation separates the grain and the aluminum in the wider position of the tube. The grain is in a 2-inch diameter case stepped down to 1.75 inches in diameter by 9.5-inch long case. The device weighs 2.05 pounds. The grain inside the case is 1.56 inches in diameter by 7.5 inches long. The grain composition consists of 57% magnesium, 38% Teflon®, 2% Shell Epon 864 epoxy binder, and 3% phenanthrene.

W205 Lot 2 Target Flare: Flare-Northern, formerly US Flare Corporation, built this target flare that is 2.0 inches in diameter and has an overall length of 10.25 inches. It is necked down to 1.75 inches in the area between 6.125 and 6.375 inches from the burning end. It contains a flare pellet approximately 1.5 inches in diameter by 8.5 inches long. The grain composition is approximately 65 parts by weight magnesium powder, 35 parts Teflon®, and 5 parts anthracene. The burning time is about 90 seconds. Flares made after July 1963 contain 3 or 4 parts by weight anthracene. Besides the manufacturer, the difference between the W205 Lot 1 flare and the W205 Lot 2 flare is mainly in the infrared composition; the configuration being quite similar.

US Flare Division of the Atlantic Research Corporation manufactured another version of this flare. The grain composition consists of 62% magnesium, 33% Teflon®, and 3% anthracene. The aluminum case is 7.5 inches long by 1.56 inches in diameter. The device weighs 2.05 pounds. This flare is used on the TDU-4/B Tow Target.

W206 Flare: The Atlantic Research Corporation developed W206 flare was designed and developed for the Aeronautical Systems Division at Eglin Air Force Base. The flare is stated to possess an improved long-wavelength infrared emission and to be relatively insensitive to changing altitude and high air velocities. It is designed for altitudes above 40,000 feet and speeds in excess of Mach 1. Ignition is by the Navy Mk 2 Mod 0 electric squib. The grain is in a stepped aluminum case that is 2 inches in diameter at the front end. The case steps down to 1.75 inches in diameter at the rear end. The case is 9.5 inches long. A layer of glass epoxy liner

separates the grain and the aluminum in the wider position of the tube. The device weighs 2.0 pounds.

W211 Target Augmentation Flare: Mr. B. Dubrow, US Flare Division of the Atlantic Research Corporation, developed this flare. He later transferred to the Space Technology Laboratory. The device is 2-inches in diameter by 13-inches long and weighs 2.5 pounds. The grain weighs 1.77 pounds, has an output of about 1000 W/sr in the 1.8μm to 2.7μm bandpass region, and has a burning time of 90 seconds. The grain composition consists of 54% magnesium gran 15, 30% Teflon®, and 16% Kel-F® wax. Two USF Model 706 Squibs wired in parallel for reliability ignite the W211 flare. The W137 flare is ignited with only one squib. No less than three W211 flares are used to augment the F9F-6K target per firing pass at 30,000 feet. The W211 flare is used extensively as an infrared source in the Pogo-Hi Target Rocket. It also is used on tow targets.

W211 Tracking Flare: This is a commercial item manufactured by the US Flare Corporation that weighs about 2.75 pounds, is about 2 inches in diameter by 12.75 inches long. It is ignited electrically.

W211/A-5 Tracking Flare: This flare was manufactured by the US Flare Corporation as a developmental item for the Air Force. It is 2 inches in diameter by 7.06 inches long, weighs about 1.6 pounds, and is ignited electrically.

W211F Flare: The Atlantic Research Corporation manufactured the W211F flare. It is used on the Q-2C drone. The grain composition consists of 54% magnesium, 30% Teflon®, and 16% Kel-F® wax. The aluminum case is 10 inches long by 1.83 inches diameter. The device weighs 2.5 pounds.

W211S Target Flare: The W211S flare is similar to the NOTS Model 712A flare and is intended for testing the increased-range Sidewinder 1C missile. It is attached to the QF-9F target drone, the Beech KDB drone and the Ryan target drone BQM-34A (old designation Q2C) jet powered aerial target with a subsonic speed. Flare-Northern Division of the Atlantic Research Corporation supplied this flare. Mr. Allen of NOTS was the task manager.

W213 Tracking Flare: Flare Northern Division of the Atlantic Research Corporation developed this device. This developmental flare is aluminum cased. It was designed with a base electrical connector and an internal insulator sleeve of paper-based phenolic material to facilitate side-by-side mounting of the flares. This is intended to permit sequencing without danger of premature ignition. Replacement of Kel-F® wax was a consideration during development. The W213 flare was one of a series of Navy and commercial flares evaluated at China Lake. In a series, which included the NOTS Model 702A flare, the NOTS Model 711A, the NOTS Model 712A, and the ARC W211F flare as well as the W213 flare, the W213 flare is the only one with higher intensity in the 2μm to 3μm bandpass region than in the 3μm to 5μm bandpass region. Ignition is with the F-ND Model 706 squib made by the

Flare Northern Division of the Atlantic Research Corporation. The flare device is 2 inches in diameter by 11.25 inches long and weighs 2.0 pounds. The grain is 8 inches long.

W216 Tracking Flare: This is a double-end burning ejected flare made by the Atlantic Research Corporation. The W216 is identical to the E216 flare. The MTV grain is 1.625 inches in diameter by 3 inches long and weighs 0.22 pounds. The composition is EW-50 consisting of unspecified materials or proportions.

W224 Countermeasure Flare aka F-ND Model W-224 Flare: This infrared flare was developed and manufactured by Dr. Waite and Mr. Reed of the Flare Northern Division of the Atlantic Research Corporation during 1966. The grain is 17 inches long by 2.125 inches in diameter and weighs 5.2 pounds. This flare is unique in configuration, consisting of an internal-burning star cast grain. The flare is part of the ADR-9A countermeasure rocket system, which is compatible with the B-52 AN/ALE-25 pod mounted dispenser. The unit, including the chaff dispenser system, the flare, and the rocket propulsion system is 6-feet long by 2.75 inches in diameter. The internal burning performance provides the infrared signal without weakening the walls of the entire structure during the 12-second life of the countermeasure system.

W251 Flare: The Flare Northern Division of the Atlantic Research Corporation developed the W251 flare. The composition, cast in an aluminum case, is a mixture of predominantly magnesium and fluorohexylmethacrylate. The metal fuel and the liquid fluorocarbon are mixed and poured into the flare casing and allowed to solidify. After aging, the composition separated from the case leading to serious deterioration of the flare. Subsequent research corrected this problem. The grain composition may be similar to that in the TAU-56/B 105E flare. The device is 2.5 inches in diameter by 19.75 inches long and weighs 4.75 pounds.

W251 106E Flare: Ordnance Research Inc. provided this flare, which simulates the W251 flare system. The unit is in the form of a 6-inch long cylinder the outside diameter of which is 1.125-inches. It contains a castable magnesium-fluorocarbon composition.

AF 08-(635)-1402 Flare: This is an infrared flare provided under a developmental contract: It was made about 1960 by the Denver Research Institute in a 2-inch diameter by 10 inch long Micarta case.

AF Part No. 60D-22348 Flare: This infrared flare was made about 1960 by Aerojet-General. It has a 2-inch diameter by 10 inch long steel case.

AF Part No. 60D-22390 Flare: This infrared flare was made about 1960 by Special Devices, Inc of Hughes Aircraft Company. It has a 2-inch diameter by 10-inch long aluminum case.

AGC Flare: Aerojet-General manufactured this flare. The grain composition consists of 64% magnesium, 34% Teflon®, and 2% anthracene. The nickel-plated steel case is 9 inches long by 1.38 inches diameter. The unit weighs 2.0 pounds. This flare is used on the TDU-4/B Tow Target.

AGX0827 Target Flare: Aerojet-General built this flare about 1963. It has an outer case diameter of 1.75 inches by 11.4 inch overall length. It is ignited by a squib through a two-contact bayonet connector in the base of the flare. The grain composition is approximately 65 parts by weight magnesium powder, 35 parts Teflon®, and 5 parts anthracene. The burning time is about 90 seconds. Flares made after July 1963 contain 3 or 4 parts by weight anthracene. Caution: The AGX0827 flare has erroneously been referred to as the TAU-50 flare and sometimes as the TAU-50/B flare during testing of the AGX0827 flare.

BATS Flare: Flare-Northern/Celesco designed the Ballistic Aerial Target System (BATS) flare. This flare, a blackbody type radiator, is an infrared augmenter for the BATS system.

BB-9 Flare: This flare is also known as the Mk 3 Mod 0 target flare.

Beech 6 Target Flare: This flare was designed and built about 1961 by Special Devices Incorporated for the Beech Aircraft Corporation's XKD2B-1 Navy drone. The Beech 6 flare was made to facilitate infrared radiant intensity measurements. It probably is similar in size to the Special Devices 5B1-5.1 infrared augmentation flare.

Beech 19 Target Flare: This flare was designed and built about 1961 by Special Devices Incorporated for the Beech Aircraft Corporation's XKD2B-1 Navy drone. The Beech 19 flare was made to facilitate infrared radiant intensity measurements. It probably is similar in size to the Special Devices 5B1-5.1 infrared augmentation flare.

CDC Model 155 Infrared Emitter: The final model of this device, made by the Cooper Development Corporation (CDC), Monrovia California was put on the pogo-hi rocket target.

DF Flare aka Type DF Flare: This Kilgore flare named type DF contains potassium nitrate, charcoal and rosin. A variant contains silicates that were added to the DF mixture. Other variants were magnesium, strontium nitrate, potassium perchlorate, sulfur, potassium nitrate, lithium carbonate, and charcoal added to the DF mixture.

F-ND Model W-224 Flare: This infrared flare was developed and manufactured by Dr. Waite and Mr. Reed of the Flare Northern Division of the Atlantic Research Corporation during 1966. It is 17 inches long by 2.125 inches in diameter and weighs 5.2 pounds fully loaded. The flare has an internal-burning cast grain

configuration. The flare is part of the ADR-9A countermeasure rocket system, which is compatible with the B-52 AN/ALE-25 dispenser.

Flare Northern Cavity Flare: The cavity flare was designed by the Air Force Armament Laboratory and was fabricated by the Flare Northern Division of the Atlantic Research Corporation. The flare is a somewhat flat cylinder 3.25 inches thick by 6.5 inches in diameter with a 1.7 in diameter hole in the center of the grain. An unspecified composition was cast in a 7-inch diameter phenolic case. Three of these flares were tested in a comparison with the Aerojet TAU-56/B flare. The results indicated similar burning times but the cavity flares had very much lower radiative intensities.

Flare Northern Rectilinear Flare: This cast flare is designed for use with the AN/ALE-11 pneumatic dispenser. A mechanical acceleration sensitive safe-and-arm initiator ignites the castable fluoromethacrylate-magnesium pyrotechnic charge. The Illinois Institute of Technology Research Institute developed the safe-and-arm initiator. The external dimensions of the flare are 2 inches high by 2.99 inches wide by 5.02 inches long. It weighs 2.2 pounds. The two 2.99-inch and 5-inch faces are formed with a grid of sixty-three 0.188-inch holes during the casting process to increase the burning surfaces by 70% for a concomitant increase in the initial intensity. The use of the methacrylate ester of 1,1,3-trihydrotetrafluoropropan-1-ol provides excellent stability up to 430 °F.

FW282 Flare: This flare contains an undefined grain composition that is loaded into a modified 40mm Mk 112 photoflash cartridge case. The grain composition in the FW282 flare is different from the grain composition in the FW355 flare. The cartridge is ejected by a Forward Air Controller (FAC) aircraft from a W/A-6 Lambert photoflash dispenser. The flare casing is 1.568 inches in diameter by 3.850 inches long with a rim diameter of 1.70 inches. In early 1974, Mr. George W. Schivley of WPAFB stated that this flare or the FW355 flare, when used in conjunction with a missile-warning receiver, would give the FAC a fully automated IRCM system.

FW355 Flare: This flare contains an undefined grain composition that is loaded into a modified 40mm Mk 112 photoflash cartridge case. The grain composition in the FW355 flare is different from the grain composition in the FW282 flare. The cartridge is ejected by a Forward Air Controller (FAC) aircraft from a W/A-6 Lambert photoflash dispenser. The flare casing is 1.568 inches in diameter by 3.850 inches long with a rim diameter of 1.70 inches. Mr. Schivley of WPAFB stated that this flare or the FW282 flare, when used in conjunction with a missile-warning receiver would give the FAC a fully automated IRCM system.

Infrared Augmenter 3090N Flare: This augmenter was made about 1967 by DynaTech Inc (DTI) Tempe Arizona, the predecessor to Talley Industries, Mesa Arizona. The Infrared Augmenter 3090N flare, a blackbody type radiator, is made for use on the Northrup MQM-74A Chukar unmanned aerial vehicle target.

K2 Flare: Kilgore made this experimental countermeasure flare.

PA-E-35392 Flare: This infrared flare is a Picatinny Arsenal development. It is 1.125 inches in diameter by 6 inches long and has a minimum burning time of 22 seconds. It was made for a special test in the early 1960s for the Electromagnetic Laboratory, Research and Development Directorate, U. S. Army Ordnance Missile Command (AMC), Redstone Arsenal Alabama. Internally, the flare has two compositions, one of which has a greater output than the other. The higher output composition is loaded so that it will burn last, that being when the missile is at the greatest range. No information about composition specifics is available.

Pace-IITRI Countermeasure Flare: This is a high-performance infrared flare developed by the Illinois Institute of Technology Research Institute for the Pace Corporation and designed for compatibility with the Lambert XM-185 photoflash cartridge ejection set. It provides a rapid rise to a very high intensity and a uniform rate of intensity decrease from the peak to burnout at 6 seconds. The design includes a pneumatic bore-riding, fail-safe igniter. Grain elements of different densities and varying burning areas are used to generate the rapid rise and controlled decay in the intensity curve. An electric primer and a black powder charge eject and ignite the flare housed in an aluminum can, which falls away when the flare is airborne. The case is 3.1 inches in diameter by 9.98 inches long. The device weighs 4.3 pounds. The grain is 2.75 inches in diameter by 9 inches long and weighs 3.20 pounds. The grain consists, in parts by weight, of 66.1 parts magnesium, 22.6 parts Teflon® #5, and 11.2 parts Teflon® #7. The first fire mixture is 97% aluminum-tungsten oxide and 3% polyvinylfluoride binder.

Target Marking Flare with no designation: In the mid 1960s, NOTS developed an infrared target marking flare for SANDIA. It was made to dispense a special dispersion of the flare material upon impact with the target. The dispersed material was required to have a specified output and duration. No additional information is known about this development.

T-245-3 Pyrotechnic Flare: Del Mar Engineering Laboratories manufactured this flare. The size is 1.75 inches in diameter by 10.5 inches long. It has electrical ignition and weighs about 1.5 pounds.

UMC-94 Tracking Flare: This is a commercial item manufactured by the Universal Match Corporation. The size is 1.75 inches in diameter by 10.5 inches long. It weighs about 1.8 pounds and is electrically ignited.

UMC-95 Tracking Flare: This is a commercial item manufactured by the Universal Match Corporation. The size is 1.75 inches in diameter by 10.5 inches long. It weighs about 0.61 pounds and is ignited parasitically.

UMC Pelleted Flare: This is a commercial item manufactured by the Universal Match Corporation. It contains 0.46 pounds (210 grams) of 0.125-inch pellets and

0.89 pounds (40 grams) of igniter mix. The pellets are bound together in a solid candle by means of the ignition composition. The ignition composition acts as a binder. Mentioned in 1956 report.

UMC-ASC 129 Flare: This is a commercial item manufactured by the Universal Match Corporation. A test version was modified for high altitude ignition. Mentioned in 1956 report.

UM-111 Flare: A test unit of this 2-inch by 2-inch by 5-inch flare was provided by Unidynamics Phoenix. The Universal Match Corporation produced it. The flare consists of a plastic case, which is expended at ignition. The grain burns over the entire surface. Ignition is by the Illinois Institute of Technology Research Institute developed inertial bore-safe igniter. The unit weighs 1.8 pounds. It fits the USAF 669A Phase I dispenser.

UNI Flares: Types I and II: The UNI flares are a series developed by Picatinny Arsenal and manufactured at the Longhorn Army Ammunition Plant, Marshall Texas. The flares were developed for compatibility with FAC and similar aircraft. The flares are small and inexpensive, with a configuration similar to the Navy Mk 50 Mod 0 flare and the Army XM-196 mini-flare. The compositions are similar to those in the Army XM-196 mini-flare. In flight, at air speeds of 140 to 190 KIAS, both flares appeared to increase in intensity with time. The design is about 1974 vintage.

UNI Flare Type I: The grain consists, in parts by weight, of 74 parts magnesium, 26 parts Teflon® and 2.6 parts nitrocellulose. The first fire is composition SI-119. The grain composition and first fire are pressed together as one increment. The grain is about 1.4 inches in diameter by 2.0 inches long and weighs 0.15 pounds. The complete unit is 1.57 inches in diameter by 3.47 inches long. For test purposes, the grains were loaded into M-112 photoflash cartridge cases.

UNI Flare Type II: The grain consists of a half and half mixture of two different compositions. One mixture is made up, in parts by weight, of 74 parts magnesium, 26 parts Teflon® and 2.6 parts nitrocellulose. The other mixture is made up, in parts by weight, of 74 parts magnesium, 26 parts Teflon® and 2.6 parts Viton® A. The first fire is composition SI-119. The grain composition and first fire are pressed together as one increment. The grain is about 1.4 inches in diameter by 2.0 inches long and weighs 0.15 pounds. The complete unit is 1.57 inches in diameter by 3.47 inches long and weighs 0.3 pounds.

Unidynamics Decoy Flare: This is a 1966 vintage decoy flare that fits the AN/ALE-29 chaff and flare dispenser. It had a limited production of 10,000 units. The Unidynamics flare was made for comparison to the NOTS EX 46 Mod 0 decoy flare. Unidynamics considers the overall flare design, grain configuration, and grain formulation to be proprietary.

United Technology Corporation Hybrid Flare: This hybrid flare consists of a cylindrical hollow flare grain wherein flowing gaseous oxygen is ignited by burning propane. The units are 24 inches long by 3.5 inches in diameter. The grains consist of polybutadiene, polybutadiene-acrylonitrile, and polymethylmethacrylate with various amounts of aluminum as a fuel. The operation of these units can be started and stopped.

XKD-2B-1 Target Augmentation Flare: Special Devices Inc. manufactured this flare. It was developed for the Beech XKD2B-1 expendable powered target drone. It consists of fifteen prepelleted increments pressed into an aluminum tube that is 2.5 inches in diameter by 20 inches long. The device weighs 8.44 pounds. The grain weighs 6.95 pounds. The first fire composition, in parts by weight, is 33 parts magnesium, 14 parts Teflon® #1, 3 parts polyisobutylene, 5 parts amorphous boron, and 45 parts barium chromate. The grain composition, in parts by weight, is 12 parts magnesium, 25 parts Teflon® #1, 6 parts polyisobutylene, 5 parts amorphous boron, and 45 parts barium chromate. The flare is ignited with two Special Devices squibs. The flare passed performance and safety tests and was approved for release for Navy use. Later however, the flares failed to sustain ignition at 50,000 feet and 70,000 feet simulated altitude.

223 Thermopot Flare: This is a thermite flare that has a burning time of 360 seconds.

5B1-5.1 Infrared Augmentation Flare: This flare was designed and built by Special Devices Incorporated for the Beech Aircraft Corporation’s XKD2B-1 Navy drone later designated the AQM-37A (USAF designation is WS-462L). The expendable powered target is capable of operation at 80,000 feet altitude and Mach 3. Very high altitude ignition is a requirement for the flare. The Special Devices 5B1-5.1 flare size is 2.5 inches in diameter by 20-inches long and weighs 8.4 pounds. The flare is spring loaded to provide a continuous advance during burning. Due to poor performance, China Lake started work on the 5B1-5.1 flare in order to develop an improved flare named the 5B1.5.1-1 infrared augmentation flare.

5B1.5.1-1 Infrared Augmentation Flare: The flare contains 6.5 pounds (2,955 grams) of prepelleted composition pressed at 9,250 psi. The improved grain composition consists of 12% magnesium, 5% boron, 45% barium chromate, 25% Teflon®, 7% glass beads and 6% polyisobutylene. Special Devices Inc. provided 3 flares with the improved composition for test firing at a simulated altitude of 70,000 feet (33.6 torr) in the China Lake High Altitude Research Project (HARP) chamber. The improved flares successfully ignited at high altitude but were deficient in their radiative output in the 3μm to 5μm bandpass region. Nevertheless, the improved 5B1.5.1-1 flare was determined to be safe for Service use. Even when using boron, the composition did not produce the desired 900 long-band to 250 short-band ratio but instead produced about a 1:1 ratio. To overcome these deficiencies, the NOTS Model 729 target augmentation flare was developed to replace the Special Devices

5B1-5.1 flare and the improved 5B1.5.1-1 flare. The Navy Bureau of Weapons designated the improved 5B1.5.1-1 flare as the Mk 37 Mod 0 Target flare.

Flare of unknown designation: This developmental flare is dispensed from an AN/ALE-20 dispenser fitted onto a B-52 bomber. The dispenser has 17 tubes, holds 52 flares at 3 flares/tube. Ejection velocity is about 80 feet/second. A commutator band is used to ignite each flare. Each flare consists of 0.42 pounds (190 grams) of a cast fluoromethacrylate. The grain burns internally.

EXCHANGE OF INFORMATION

NOTS Technical Reporting

The Naval Ordnance Test Station was commissioned during World War II in November of 1943. The Test Station is an outgrowth of the rocket program being conducted at Inyokern, China Lake by the California Institute of Technology (Caltech) for the Office of Scientific Research and Development (OSDR). From the time of its commissioning, until the end of WW II in August 1945, NOTS did little technical reporting, for its main role was to support the weapon development and pilot production work of Caltech. Caltech published the reports between 1943 and 1955. With the transfer of most of the Caltech work to NOTS in 1955, the Station began its own reporting program. The NOTS Technical Publication series starts in 1958.

Infrared Information Symposia

The importance of the growing interest in research and development of military technologies and their rapid expansion is evidenced by the formation of a symposium series in 1949 known even today as the IRIS conferences. The Office of Naval Research (ONR) sponsors the Infrared Information Symposia (IRIS). These meetings are open to U. S. government employees and U. S. government contractors. The conferences address infrared topics such as detectors, active and passive jamming, expendables such as chaff and infrared decoy flares, measurement techniques, and all associated equipment development. The history of IRIS and the history of ONR can be found in the proceedings of IRIS.[8]

Meetings on Infrared Suppression

In October 1960, ONR sponsored the First Meeting on Infrared Suppression. Attendance eligibility is similar to that of the IRIS symposia. The second meeting took place in June 1962. Lockheed, Burbank, California, hosted the Third Meeting on Infrared Suppression. Mr. Francis Linton of the Wright Air Development Center, WPAFB and Mr. Regelson of NOTS China Lake were the co-chairmen for the Third Meeting on Infrared Suppression.

Pyrotechnics Lecture

In February 1955, Dr. David Hart while at the Samuel Feltman Ammunition Laboratories at Picatinny Arsenal, Dover New Jersey presented Research and Development Lecture No. 24 entitled Research and Development Progress in Pyrotechnics. Formally organized since 1951, the Picatinny Arsenal Pyrotechnics

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[8] The history of IRIS and the history of ONR can be found in the Proceedings of the Infrared Information Symposia Volume 1, Number 1, 1956 and Volume 21, 1977.

Section conducted research and development of pyrotechnics. The Pyrotechnics Section is organized into Engineering, Chemical Research and Radiation Research units. Picatinny Arsenal, a U. S. Army agency, is responsible for research and development of all military devices and compositions for the Army and the Air Force, as well as all pyrotechnic compositions for the Navy. In fact Picatinny Arsenal only supplied a limited number of compositions and devices to the Navy. Tracking flares for trajectory observation of rockets and guided missiles are mentioned as a pyrotechnic category in Dr. Hart's lecture. He did not provide information about work on these items for the Navy.

During Lecture # 27 in February 1956, Dr. Hart reviewed development of delay compositions, the stoichiometry of fuels (metals and non-metals) and oxidants used in delay compositions. He pointed out that black powder customarily used to make delays, is an explosive and presents some hazards. To overcome the disadvantages of black powder as a delay powder, Dr. George C. Hale at Picatinny Arsenal, began work in 1929 on the development of non-gaseous delay powders, making use of inorganic exothermic reactions similar to those used in thermite mixtures. The first non-gaseous delay powder was developed in 1931 for the M16-A1 primer detonator used in a bomb fuze. It contained red lead, silicon, and glycerine, the latter added as a binder. Even in small quantities, organic binding agents such as glycerine and linseed oil produce a significant amount of gas upon combustion.

Symposium on Basic Pyrotechnics Research

On 14-15 February 1957, Picatinny Arsenal hosted a symposium on Basic Pyrotechnics Research.

Semiannual Interstation Pyrotechnics Conferences

The purpose of these Conferences is to disseminate new information on techniques, interchange of ideas in research and development, and discuss mutual problems in the field.

The Third Semiannual Interstation Pyrotechnics Conference was held 5-7 April 1960 at NOTS. During the 1960 conference, Mr. Smith of NAD, Crane presented problems encountered in making luminous intensity and infrared measurements. The test tunnel configuration, positioning of the test unit, smoke obscuration, smoke exhaust, and measurement instrumentation are some of the topics discussed. Mr. Pennington of NOTS presented an overview of pyrotechnic target augmentation at NOTS. Mr. Eli D. Besser of NOTS presented information about mixing variations using the Simpson Muller mixer, the Lancaster Muller mixer, and a 40-gallon High Explosive Melting Kettle. Mr. Besser reported that volatility and migration of Kel-F® wax, which has a melting point of 100-140 °F, does not occur. Later, problems with Kel-F® wax did arise making the Viton® A replacement for Kel-F® wax even more important. Mr. Bernard E. White of NOL White Oak described work on development

of delay columns. Igniter mixes called A1A, F33B, and FA878 were considered along with D-16 delay powder. Mr. Rivette described the variation of flare performance with diameter. Mr. Allen of NOTS reported on a flare case material study. Materials considered were stainless steel, aluminum, magnesium, brass, Lucite, Teflon®, and Micarta. Mr. Russell N. Skeeters described ordnance fixes for HERO, just 3-years after the USS Kearsarge CV33 incident.

The Fifth Interstation Pyrotechnics Conference was held 5-6 December 1961 at NAD, Crane. Mr. Allen of NOTS presented a paper on an improved flare composition, that being 54% magnesium gran 16, 30% Teflon® #7 (35μm), and 16% Viton® A. This is the “improved” formula, which came into being with the shock-gel process. The shock-gel process was reported in 1959.

The Seventh Interstation Pyrotechnics Conference was held 21-23 January 1964 at NAD, Crane. Mr. E. M. Kane of the Naval Missile Center (NMC), Point Mugu, California presented papers on spectral analysis of flares and infrared flare performance. There also is a presentation on scanning spectroscopy by Mr. Benham of NAD Crane.

The Eight Interstation Pyrotechnics Conference was held 8-10 December 1964 at the fleet Antisubmarine Warfare School in San Diego California. Mr. Allen of NOTS presented a paper on new possibilities in underwater flare formulations. He reported that composition PL6239 was underwater for 69 days and still ignited. That composition consists of 54% magnesium gran 16, 30% Teflon® #7, and 16% Viton® A.

PRINCIPAL RESEARCH AND DEVELOPMENT AGENCIES

Scientists, engineers and technicians at China Lake pioneered target flare, augmentation flare, and decoy flare development in addition to other technologies. It naturally followed that there would be a concentration of developmental effort of these devices at China Lake. In the early times, the NOTS effort was the result of their local needs and those directed by Navy headquarters in Washington DC. Because of their expertise, NOTS investigators were also able to undertake tasks from the Army and the Air Force. It should be noted that there was a capacity within NOTS to physically accomplish tasks involving energetic materials such as propellants and flares. The Air Force did not have a capability within their organization to conduct developments involving energetic materials. As a result, the Air Force conducted their flare development by contract with outside research institutes. Because of these circumstances, the major Navy efforts were performed at NOTS and NAD Crane, the Army efforts were performed by the Samuel Feltman Ammunition Laboratories at Picatinny Arsenal and by the Universal Match Corporation, and the Air Force conducted their decoy developments under contracts mainly with the Armour Research Foundation and Denver Research Institute.

Naval Ordnance Test Station (NOTS)

About 1969, the Naval Ordnance Station, China Lake became the Naval Weapons Center (NWC), China Lake.

Early Tracking Flares

NOTS was involved with infrared target augmentation since 1954. They needed to provide a target source for the F6F-5K drone. The T-131 tracking flare was the first infrared source for drone use. Multiples of the T-131 tracking flares were needed to provide a suitable target. In 1956, the Army reported an M136 (T131) tracking flare with illuminating composition.

Initially, flares were needed for tracking in the visible portion of the electromagnetic spectrum. Later, infrared radiators were needed to enable tracking in the infrared region. Tracking flares serve two major purposes in missile research. They facilitate tracking by optical instrumentation operators who might not otherwise be able to track the missile in flight at high altitude or under all but the best atmospheric conditions. Also, data reduction personnel would often find it difficult, if not impossible, to locate events on the film records if there were no flares to provide a reference mark on the film. In 1960, Mr. Pennington of NOTS stated that the T-131 flare, the Mk 21 Mod 0 flare and the NOTS Model 702 flare are the most widely used tracking flares at NOTS.

The Shock-Gel and Extrusion Process

In 1959, a shock-gel process was discovered that could produce an improved infrared composition that contained Viton® A instead of Kel-F® wax. The improved composition consists of 54% magnesium gran 16, 30% Teflon® #7 (35μm), and 16% Viton® A. This composition has less electrostatic sensitivity than the Kel-F® formula. It can easily be extruded at temperatures from 150 °F to 225 °F as well as being compression molded. The extruded forms have tensile strengths and elongation that withstand forces and vibrations frequently experienced during use such as during a sled-test run. In addition, the extruded forms can easily be machined. This discovery became the foundation for processing of infrared compositions and future infrared flare development. The shock-gel process, sometimes known as the coacervation process, continues in use today.

In 1962, Mr. Allen of NOTS described the shock-gel process as follows: Viton® A, a copolymer of vinylidene fluoride and hexafluoropropylene, also known as perfluoropropylene, is dissolved in acetone to form a solution ranging from 8 to 20% solids. The required quantities of magnesium and Teflon® are stirred into the appropriate quantity of Viton® A solution. This slurry is quickly added to a large volume of rapidly agitating hexane. By this treatment, all the material is precipitated in a granular form. After one or two more washes with additional hexane, the material is collected and dried. While drying, the material is usually passed through a brass screen with 0.250-inch openings.

The granular material is then heated to 190 °F, placed in the barrel of an extrusion press (heated to 225 °F), and extruded through the die. The extrusion pressures and flow rates are dependent upon (1) the total binder content, (2) the Viton® A to Teflon® ratio, (3) the particle size and particle shape of the filler, (4) the ratio of the die area to barrel area in cross section, and (5) the shape and design of the die itself. After extrusion is completed, the material may be machined into desired lengths and shapes as required.

The shock-gel process is also used at China Lake to extrude propellants with fluorocarbon binders. They demonstrated extrusion of a composition consisting of Teflon® and Viton® A as binders, aluminum and zirconium as fuels and ammonium perchlorate as an oxidizer. Work continued at NOTS in 1966 and beyond to improve the procedure. The hazards of alcohols in wet mixing of magnesium compositions were recognized and studied.

Standard and Improved Infrared Composition

Prior to about 1959, the infrared composition that had evolved from an illumination composition consisted of magnesium, Teflon®, and Kel-F® wax. That formula was considered by NOTS to be their “Standard”. This “Standard” infrared composition consisted of 54% magnesium gran 16, 30% Teflon® #1 600µm, and 16% Kel-F® #40 wax. The tensile strength of this composition is quite low and the density is only about 90% of theoretical. The composition is quite hazardous, exhibiting a 50%-point electrostatic sensitivity of 0.76 joules. Flares of this composition are usually made by compression molding. There was a need to improve this composition to overcome its deficiencies. About 1955, while considering many variations of the infrared composition, mixtures of 48% aluminum-52% Teflon®, 56% boron-44% Teflon®, and 54% zirconium hydride-46% Teflon® were studied.

A new infrared flare composition for tracking flares was first conceived by Mr. Julian of NOTS China Lake about 5 July 1960. It was extruded for the first time on 10 November 1960. This new infrared composition consists of magnesium, polytetrafluoroethylene, and Viton® A. It provided a substantial increase of radiated energy in the infrared over former tracking flare formulae that typically consisted of an illuminating flare composition or a magnesium-Teflon®-Kel-F® wax composition. The new composition by Mr. Julian is the first with the exact formula 54% magnesium, 30% Teflon®, and 16% Viton® A. He also explored an alternate infrared composition, that being a binary mixture of 36% Viton® A and 64% magnesium. That composition, which also could be extruded, burned faster than MTV with a higher radiative output but with a lower energy output in the measured wavelength band. Ignition could be achieved at 80,000 and 100,000 feet altitude with an ignition composition consisting of 10% boron and 90% barium chromate. Mr. Julian mentions the shock-gel process for making infrared composition in his descriptions of the above compositions.

On 21 November 1961, Mr. Judson H. Eldridge and Mr. Julian[9] of NOTS filed for a patent which discloses how additives to Teflon® such as Viton® A can be used to extrude Teflon® easily. They mention adding fillers such as metal, carbon and inorganic salts to the binary Teflon®-Viton® A composition and demonstrated extrusion of the composition containing tungsten and lead fillers. This patent can be considered to be the invention of the flare compositions that could be fabricated by an extrusion process that facilitated the decoy manufacturing process.

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[9] Eldridge, Judson H. and Elmo C. Julian. Polytetrafluoroethylene Composition Containing Vinylidene Fluoride-Perfluoropropylene Copolymer. U. S. Patent 3,291,864. 13 December 1966. The patent was filed on 21 November 1961.

Various Developmental Tasks at China Lake

Efforts at China Lake to develop new flares, to make product improvements to existing flares and to better understand the associated technology was a continuing process. Many tasks related to flares often were ongoing at the same time with a wide range of objectives. Some samples of these projects although incomplete are described below.

As flare performance optimization studies continued, NOTS investigators developed triangular compositional diagrams to show the optimum infrared formulae using magnesium, Teflon®, and Viton® A (MTV). Similarly, a triangular diagram was constructed to show the burning rate as a function of Teflon® particle size. Recommendations included replacement of the Kel-F® wax with Viton® A and incorporation of graphite nuclei systems such as anthracene and phenanthrene to enhance the yield, as reported by the Air Force.

During attempts to formulate infrared radiating compositions, NOTS researchers learned that a composition originally formulated for radiation in the visible could be converted to a composition that would radiate in the infrared by adding hollow polystyrene beads. An example of such a composition is PL 6502. This method to improve flare radiative performance never was implemented.

As part of the effort to improve processing of infrared flare materials, during the mid 1960s, Mr. Breslow and Mr. S. R. Stanley of NOTS conducted isostatic-pressing studies of large flares under the sponsorship of Mr. William Lurie in Naval Air (NAVAIR) Headquarters.

NOTS investigators also undertook tasks different from but related to infrared decoy technology. About 1963, the Marine Corps had a requirement for a night attack flare that would be an illuminating flare with a low rate of descent or would hover. To fill that need, NOTS researchers considered a hot air balloon and rotary wing suspension. They also considered the Army T-10E4 (M138) aircraft parachute flare and the T-10E6 (M139) aircraft parachute flare for this application.

A recurring problem with decoy flares was the failure to ignite at high altitudes where flares are required to operate. As part of the studies to aid ignition, Mr. Foote and Mr. Wiebke of NOTS studied hot bridge-wire initiation of magnesium-fluorocarbon composition PL 6239, composition PL 6328, and composition PL 6503 for Mr. J. G. Boyes at SANDIA.

There also was a need for a wheels-up warning system. Such a device could be a mortar at the end of runways at the China Lake Naval Air Facility. The double star AN-M37A2 aircraft illumination signal was considered for this application. A full description of this concept is provided in the Mr. Sanford R. Allen and Mr. Kenneth R. Foote, China Lake, U. S. Patent 3,181,822 for “Wheels-Up” Flare Warning System of May 4, 1965.

In 1967, Dr. Handler of China Lake reported on the development of the NOTS Model 400A decoy flare intended for launching from the AN/ALE-29 dispensing set. The goal is for the flare to defeat the ATOLL missile using the Sidewinder 1A as a surrogate. The flare's composition consists of 55% magnesium, 30% Teflon®, and 15% Viton® A. The design includes a pull wire for ignition, which is similar to pull wire igniters used in Army devices. Flight tests were scheduled for May of 1967.

Early flare developments were aimed at providing protection in the infrared 2μm to 3μm bandpass region. As missiles improved, the threat moved to also operate in the infrared 3μm to 5μm bandpass region. In 1968, Mr. Hanzel, Dr. Handler and Mr. Harp set out to develop a family of infrared flares that were effective in the 3μm to 5μm bandpass region. They considered changing the burning mode to a much higher rate, burning more material, lengthening the flare by two inches, altering the AN/ALE-29 dispenser to "squarish" holes, and altering the composition to improve efficiency. The Mk 46 Mod 0 flare, which was in production at the NAD Crane in 1968, is the first flare developed with the above objectives. They discussed the need for 120-150 decoy flares on an aircraft operating in a dangerous area. That perhaps is the first time that IRCM investigators suggested that the number of decoy flares that could be carried by aircraft of that era would be insufficient to provide complete protection.

Dr. Handler and Mr. Hanzel of NOTS also considered making a longer flare grain and composition variants. For the Mk 46 Mod 0 flare with the larger grain, they considered four different igniters, namely the pull wire, stab primer, electric primer and the pilot flame. Work also was directed toward an improved composition or a grain configuration that would yield a 100-microsecond rise time. One such improvement that was mentioned in a 1969 report was to form twelve longitudinal slots on the exterior of the grain to get a quicker rise time. Variations of this concept proved in time to be an effective way to adjust performance.

As part of the continuing effort to improve decoy flares, NWC extruded grains with the Mk 46 Mod 0 flare type exterior and an 8-point star interior with six different ignition configurations. By late 1970, NWC was exploring many design concepts for a flare intended to perform in the 3μm to 5μm bandpass region. They removed the pull wire and designed the case and the impulse cartridge to be an integral piece. They tested many grain designs, including a 4-slot, 24-slot design and star perforation designs.

In early 1970, Navy Headquarters proposed that the new flare being developed must remain the same length in order to be compatible with the AN/ALE-29 dispenser. That meant the new flare needed to be 1.4 inches in diameter by 5.875 inches long. Since the flare is volume-constrained to the size of the holes in the dispenser block, they needed an alternate means to achieve higher performance through increased volume-efficiency. This resulted in the need for superior flare material, shorter burning requirements, or altering the reduced serviceability of

existing flares caused by degradation at altitude and velocity. The investigators used composition PL 6328 for the grain to achieve a higher performance in their new flare.

As decoy flare testing continued at NOTS, additional deficiencies or weaknesses in flare performance were uncovered. One of these was the affect of airflow on flare performance. To evaluate this feature, in mid-1970, a team of investigators was assembled to conduct laboratory studies of the airflow effect. The team consisted of Dr. Elliott Raison at the Illinois Institute of Technology Research Institute (IITRI), Mr. Balwanz at the Naval Research Laboratory (NRL) and researchers at NWC China Lake. The team confirmed the marked reduction of infrared radiant intensity when flares are exposed to airflow. This may be the first time this characteristic of decoy flares was confirmed.

One of the observations resulting from the continuing test efforts was that a decoy plume with a large radiating area would have some advantages over a compact plume, the latter often referred to as a point source. NWC investigators decided to study an extended area decoy flare in 1971. They used a mixture of gasoline with Navy aircraft fuel JP-5 in a 1:2 ratio to saturate sisal twine strands and cotton strands. They wrapped these in foil and then put them into the container. They tested this by attaching to the hook of the helicopter hoist line. The radiant energy from the burning area decoy broke the lock of the AIM-9C Sidewinder missile, which had been locked on the helicopter engine exhaust. The area decoy plume is about 15 inches across by 4 inches high. The radiant intensity on the 3μm to 5μm bandpass region is slightly higher than the 2μm to 3μm bandpass but 4 times higher than the 8μm to 12μm bandpass region. The results indicate that the basic idea of a low temperature, broad profile, extended area infrared signal may provide significant decoy value for protection of slow flying aircraft.

Another developmental thrust at NWC mentioned in a 1972 report involved the pyrotechnic generation of infrared radiation in the long wavelength region of 8μm to 12μm bandpass region or 8μm to 14μm bandpass region. To achieve this objective, investigators made a composition of aluminum and plaster-of-paris. That mixture is also known as Alcast. They made other compositions with Celcon®, boron, red phosphorus, silicon, molybdenum trioxide, calcium-silicon alloy, aluminum-calcium oxalate, ammonium formate, ferric oxide, potassium persulphate, sulphur, strontium carbonate and calcium carbonate.

Naval Ammunition Depot (NAD 1958-75), Crane Indiana: (NWSC 1976-1992)

In an effort to better understand the performance of infrared compositions, in 1962 Mr. Jerry R. Kemp and Mr. John W. Feagans of NAD Crane performed a statistical analysis of the composition developed by NOTS for the Mk 28 Mod 0 tracking Flare. They varied the magnesium granulation, case diameter, and ratio of the magnesium-Teflon®-Kel-F® wax ingredients to find the effect on infrared emission and burning time. With the information gathered they attempted to construct empirical equations to predict flare performance.

Mr. Arnold and Mr. Kemp of NAD Crane evaluated the Mk 28 Mod 3 target flare performance about 1964. They tested the flare from ground level to a simulated 70,000-foot altitude in four increments. The altitude was simulated in a vacuum chamber.

Based on a Rocketdyne process, a Quickmix laboratory mixing technique was applied to the magnesium-Teflon®-Viton® A composition and delay compositions during 1969. A stirring motor in a beaker provided the mixing action. Heptane or acetone was the carrier liquid. Mr. Richard Kirby of NAD Crane reported the process works well with Viton® A and that they observed less batch-to-batch variability as compared to batches made by production processes.

In 1970, Mr. Sherman E. Dare and Mr. Patrick Arvin of NAD Crane converted a Hobart Model N-50 electric mixer to an air drive for preparation of pyrotechnic compositions. The Hobart is a planetary action mixer. The air drive was introduced for safety reasons.

About 1981, Mr. Donald R. Hazelton and Dr. Henry A. Webster III of the Naval Weapons Support Center (NWSC) Crane Indiana described design parameters for an outdoor transient velocity windstream test apparatus. The facility provides the ability to measure the radiant output of flares in an airstream of up to 0.9 Mach for nine seconds. The objective of this ground test is to obtain information about the degradation of the flare output due to the windstream when tested in the airborne mode. Later, the facility was upgraded to achieve 0.9 Mach for about 12 seconds.

In 1980, Mr. Kent Hammond of NWSC Crane reported the qualification of ground magnesium as an alternate to atomized magnesium in production flares. In 1981, MJU-8/B flare measurements were being made of production units by Mr. Forest Burton of NWSC Crane. A little later, Dr. Webster of NWSC Crane obtained an ultraviolet spectrum of the Mk 46 Mod 0 decoy flare and identified the atomic magnesium line in that spectrum and molecular emitters such as magnesium fluoride, magnesium oxide and magnesium hydroxide. A 1982 report describes an effort by Dr. Webster to obtain a statistical analysis of infrared flare production lot data, for example the MJU-8/B decoy flare. Earlier in 1979, he obtained the spectral distribution and an ultraviolet spectrum of an illuminating type pyrotechnic and in 1976 he obtained visible spectra of the Mk 46 Mod 1A decoy flare.

Denver Research Institute (DRI)

For many years, the Denver Research Institute received contracts from the Air Force for investigating the fundamental aspects of decoy flare combustion. The source of most of these contracts was Mr. Sarnow of WPAFB. The thrust of the tasks was to find new and improved infrared flare compositions that might be applied to flare developments for bomber protection. This meant the flare compositions needed to produce a large infrared signature and that these flare compositions could be ignited at very high altitudes while operating a high Mach numbers. The breath and depth of these studies is astonishing. Almost all elements in the periodic table were brought into consideration, as were almost all conceivable combinations of fuel and oxidizer. The thermodynamic features of these reaction combinations were tabulated. Some of the tasks are described below.

In 1959, a two-year contract was awarded to the Denver Research Institute for an Infrared Decoy Study with Dr. Robert W. Evans as the Principal Investigator. Mr. Sarnow as the Air Force Project Engineer at WPAFB sponsored the work. This was a project to study a wide variety of fundamental properties and behavior of the magnesium-Teflon® composition as described next.

Test pellets, 0.5 inch in diameter by 3 to 5 inches long, were prepared with magnesium and Teflon® but with no binder. The pellets were pressed at a dead load of 3000 - 4000 pounds. They attempted to determine the solid and gaseous products, the spectral distribution of the radiated energy and the temperature of the combustion. The combustion experiments were conducted in ambient air, flowing air, flowing nitrogen and flowing oxygen. By chromatographic analysis and other techniques, they accounted for all the magnesium but only about 85% of the fluorine in the solid reaction products. The difference was attributed to afterburning of the fluoride species with surrounding oxygen and nitrogen. The spectral distribution resembles a gray body of high emissivity with some selective emission around 2.5μm wavelength. The temperature immediately above the burning surface is in the range of 2200 to 2400 K.

The experiments also included burning the pellets in a six-foot diameter by six-foot long chamber capable of operation up to a simulated altitude of 250,000 feet. The Denver Research Institute team reported a slowdown of the burning rate and a spectral shift toward longer wavelengths as the altitude increases. They studied the linear burning rate of the pellet in argon and oxygen atmospheres and measured the burning surface temperature at different simulated altitudes (ambient pressure). They also explored how inhibiting coatings and axial holes affected pellet combustion and they attempted to measure the heat of activation of the magnesium-Teflon® mixture.

The Denver Research Institute team determined the intensity and spectral distribution of the radiation produced by flares made up of finely divided metal fuels and oxidizers for various ambient conditions. They discussed the contribution of

specific emitters and emission from various areas of the flame for simulated altitudes up to 150,000 feet and used mechanistic and kinetic studies to develop a proposed reaction sequence to qualitatively explain the reduction of radiation with altitude.

Another task mentioned in a 1961 report was an attempt to incorporate Viton® A into the magnesium-Teflon® mixture. Viton® A contains 65% fluorine and has a specific gravity of 1.85 g/cc. The Denver Research Institute team ground Viton® A that had been embrittled with dry ice without the benefit of a solvent medium. The ground Viton® A was put into solution of methyl ethyl ketone (MEK) and then was precipitated with ethyl alcohol or a water solution in MEK. Next the magnesium-Teflon® mix was added to the precipitated Viton® A, after which the pellet was cast into its container, and finally the solvent was removed. This technique never was implemented. The shock-gel process being developed at China Lake during the same time period eventually was chosen as the preferred process.

During their studies, Denver Research Institute investigators made an attempt to improve performance by changing the composition itself. They studied the effects of varying the magnesium from 36-70% and varying altitudes up to 100,000 feet. They recorded spectra, burning time, temperature, and radiated energy. They did not observe any effect by adding barium oxide but adding magnesium perchlorate appeared to be beneficial at altitude.

In a follow-on contract to the Denver Research Institute from Mr. Sarnow of WPAFB, Dr. Evans studied the fundamental characteristics of magnesium/Teflon® pressed flares. He reported (1) magnesium oxide forms instead of the expected magnesium fluoride when afterburning in air occurs, (2) replacement of Teflon® with Viton® A is not superior, (3) present methods of adding Viton® A to magnesium/Teflon® mixtures results in a product that is mechanically weak, (4) an equation for conduction of heat from the reaction zone, (5) that more radiant energy is emitted when the formula is nearer to stoichiometric than the 50:50 magnesium to Teflon® ratio being used in the study, (6) fuel rich mixtures are better than stoichiometric and produce a faster burning rate, (7) radiant energy output is best when there is afterburning with an adequate oxygen supply from the surrounding air and (8) that 50% of the radiation is from 15% of the projected flame area.

Experimental investigation of infrared radiating sources continued at the Denver Research Institute in the early 1960s pursuant to contracts from WPAFB with Mr. Sarnow as the project monitor. Mr. Robert M. Blunt and Dr. Evans of the Denver Research Institute determined heats of combustion of solid and gaseous products of the magnesium-Teflon® reaction and did a literature survey to locate information dealing with radiation from solids suspended in flames. Another contract with the Air Force emphasized the experimental investigation of infrared radiating sources. In this work, with a third investigator namely Mr. Jim P. Kottenstette of DRI, the Denver Research Institute team explored the fundamental technical, chemical and thermodynamic aspects of the magnesium-Teflon® reaction. They studied the

reaction products, attempted several methods to determine the activation energy, analyzed the spectral distribution of the radiated energy and explored the effects of particulate matter in the flame.

Mr. William H. McLain and Dr. Evans of the Denver Research Institute conducted a spectrometric evaluation of metal containing fuels in the early 1960s for Edwards Air Force Base California. They developed methods to use optical spectrometric techniques to evaluate the extent of thermal and chemical equilibrium for a methylamine-beryllium borohydride (Hybaline B-3) fueled rocket motor. They analyzed band and spectral line structure of selected species along with the total radiation distribution emitted from a small rocket motor. They compared experimental data to predicted and made estimates of chemical reactions that might be taking place. They observed two vapor phase combustion products in the visible, namely boron dioxide and beryllium oxide. In the infrared, they observed carbon monoxide and carbon dioxide selective emissions and emissions at the infrared wavelengths of 5.4µm and 5.9µm that they attributed to boron hydride oxide, boron oxide hydroxide, and boron monoxide. Mr. McLain and Mr. Ralph E. Williams attempted to determine whether exhaust plume species could be analyzed with a rapid scanning spectrometer and whether plume temperature profiles could be obtained utilizing Wien's Radiation Law or by a rapid-response multi-channel ratio pyrometer. They adapted the NASA propellant performance program onto their Burroughs B-5000 computer. They reported on photometric studies of the Hybaline B-3 air diffusion flames at ambient temperatures and studies of acetylene-oxygen flames to which boron and beryllium powders were added. From these flames they observed boron monoxide, boron dioxide, and beryllium oxide as the principal emitting species. They tabulated possible species in the visible and infrared from Hybaline B-3-nitrogen tetroxide, and hydrogen peroxide propellant systems and described a rapid-response three-color optical pyrometer that they used in support of their work.

By the mid 1960s, an understanding of missile operations and radiation emission from pyrotechnic flames was becoming more mature. As a result, the objectives of new research contracts became more specific. One such an example is the project sponsored by Mr. William S. Cronk of the Air Force Armament Laboratory at Eglin Air Force Base with the Denver Research Institute. Mr. Robert E. Knight, Mr. Blunt and Dr. Evans of DRI undertook the task to develop a pyrotechnic source that radiated in a narrow wavelength band and emitted selectively. The preferred radiation produced must be in the areas of interest, namely (1) in the specific infrared bands that result from the radiation produced by aircraft (and spacecraft) and (2) must also operate in the sensitive region of the detector used in the missile guidance system. The requirement of this effort may have been the first attempt to create a pyrotechnic decoy that radiated in regions that correspond to radiative regions where aircraft radiate. Today one might identify such a decoy as a "spectral or color adapted" flare. Perhaps in the mid 1960s the researchers did not appreciate how important it would be to have a decoy that would radiate with the proper spectral properties. The Denver Research Institute team observed in the

magnesium-Teflon® flare that the fluorine reaction competed with ambient oxygen and thus not much of the desirable carbon dioxide species was formed. To counteract this, they added manganese dioxide, barium oxide, cupric oxide, potassium perchlorate, and potassium nitrate to the magnesium-Teflon® formula in an effort to introduce more oxygen into the combustion reaction. These additions did in fact cause more carbon dioxide to be formed and they showed spectra to prove this.

As another approach, the Denver Research Institute team considered solid emitters such as boron nitride and discussed the disadvantages of such an approach. They also considered liquid flares. To explore other approaches, they compiled thermodynamic properties of hydrogen, carbon, nitrogen, silicon, phosphorus, and sulfur compounds that were stable at 3000 K and that emitted in the infrared. In the course of their investigations, they demonstrated that selective radiation due to carbon monoxide and carbon dioxide could be obtained from the magnesium-Teflon® reaction if they added an oxygen containing oxidizer such as potassium nitrate. As an additional approach, they suggested micro-encapsulation of perchlorofluoride into a fuel matrix. To show their insight into this problem, I quote, "the use of perchlorofluoride is suggested because it contains three oxygen atoms in addition to a chlorine atom and a fluorine atom. With a hydrocarbon fuel, carbon monoxide and carbon dioxide should be produced. While some of the hot carbon dioxide radiation is absorbed by the atmospheric carbon dioxide, much is still transmitted as the hot carbon dioxide peak shifted to the longer wavelengths (especially if carbon monoxide is present). As carbon dioxide is an intense thermal emitter and as part of the carbon dioxide radiation may also be due to chemiluminescence, it is desirable to include carbon dioxide."

Mr. Williams and Dr. Evans of the Denver Research Institute conducted an experimental investigation of infrared radiating chemical sources under the sponsorship of Mr. Sarnow of the Avionics Laboratory at WPAFB about 1963. They selected eight reactions for study based on volumetric enthalpies. These are reactions between aluminum-manganese dioxide, aluminum-cupric oxide, hafnium-manganese dioxide, magnesium-manganese dioxide, titanium-barium nitrate, titanium-cupric oxide, titanium-manganese dioxide, and zirconium-manganese dioxide. They obtained X-ray diffraction patterns and electromagnetic spectra and analyzed the gases and solids from the reactions. They studied aluminum fluoride, aluminum chloride and silver difluoride as additives and effects of gamma and neutron irradiation on manganese dioxide. Of the eight reactions, titanium-manganese dioxide exhibited the highest apparent radiation in watts per steradian and the highest radiant energy density in watt-seconds per cubic centimeter. These data nearly approach the volumetric efficiency of the magnesium-Teflon® reaction.

In the early 1960s as reported in 1965, Mr. William A. Schmeling and Mr. Knight of the Denver Research Institute started to explore different concepts for enhancing the performance of decoy flares. Mr. Cronk of Eglin Air Force Base supported this effort. They wanted to explore methods affecting the post combustion of

magnesium-Teflon® compositions and some non-carbon containing flares with the intent of enhancing the flare radiation of the electromagnetic spectrum as a function of altitude. Some of the approaches were to (1) include a two flare set-up wherein the plumes from the two flares positioned at 180 degrees impinged on one-another ("butting"), (2) introduce gas, liquid and solid additives to the post combustion zone such as carbon bisulfide, carbon tetrachloride, and benzene, (3) arrange a three-flare 120 degree "Y" opposed set-up and a four-flare cross opposed set-up, and (4) arrange a "tepee" of three-flares. The idea in all of these is for the plumes from individual flares to impinge on other plumes so that the point of intersection of the plumes would cause an increase in temperature resulting in increased radiation from the collective event. The "Y" and "cross" arrangements were the most promising. In addition, to get selective emissions, they explored magnesium-sodium nitrate and magnesium-potassium nitrate compositions that intrinsically were void of carbon; hence carbon emission would be reduced. Their goal as the work progressed was to get selective narrow-band high efficiency radiating characteristics. Their emphasis was on post-combustion phenomena, methods to enhance output energy, and to concentrate that energy into specific electromagnetic regions. To enhance the output, they considered gaseous additives such as oxygen, nitrogen dioxide, ammonia, chlorine, hydrogen chloride, chlorine trifluoride, sulfur dioxide, hydrogen sulfide, and propane. Dr. Hal Waite of Flare-Northern provided test flares for some of these experiments, which consisted of 45% fluoroheptylmethacrylate, 50% magnesium, and 5% isoviolanthrone made by the cast process.

In the mid-1960s, Mr. Sarnow of WPAFB sponsored a contract to study new flare materials. Mr. Williams and Dr. Evans of the Denver Research Institute and Mr. Stanley Lehrer of Astrosystems International Inc. conducted the work. To get around the greybody radiation from solid-solid reactions, they formulated liquid decoys from monopropellant nitromethane and even considered deuterated compounds such as deuterium chloride and deuterium perchlorofluoride. They reported boron compounds as being promising, these being compounds such as trimethylborate, triethylborane, and methylamine-beryllium-borohydride. Radiation from these occurred at wavelengths of 4.9μm and 5.4μm, a desirable radiative region.

Armour Research Foundation (ARF): **Later became the Research Institute of IIT (IITRI)**

Dr. Katz and Dr. Elliott Raison of the Armour Research Foundation (ARF) at the Illinois Institute of Technology (IIT), Chicago Illinois, under contract to the Weapons Guidance Laboratory of WPAFB in late 1958, conducted an extensive 1-year task to originate and develop concepts for infrared flares optimized to radiate effectively in the 3.0μm to 5.5μm bandpass region. That study was to be primarily theoretical and analytical. The Armour Research Foundation team considered infrared sources classified into two groups, namely thermal and quantum. The Balls of Fire flare and secondary sources based on light scattering are examples of the first group. Chemiluminescence, fluorescence, and solid semi-conductor radiators are examples of the second group.

In addition to magnesium-Teflon® reactions, they also considered aluminum reactions with tungsten oxide, cadmium oxide, and ferric oxide. Some additional technology areas considered were thermochemistry, blackbody radiation, solid chemical reactions, gaseous chemical reactions, gaseous discharge, chemiluminescence, infrared fluorescence, controlled emissivity, controlled burning, combustible aerosol clouds, and light scattering. They also considered (1) a liquid flare made with magnesium powder mixed with a liquid polymeric form of Kel-F® wax and chlorotrifluoroethylene and (2) a cone shaped flare with an apex angle of 31 degrees. Presumably the latter shape would have less drag than a sphere and thus would separate from the aircraft more slowly in the horizontal coordinate.

In early 1960, Mr. Sarnow of the Air Research and Development Command WPAFB, awarded a contract to the Armour Research Foundation to develop the RR-96(XY-1)/Al flare for very high altitude applications. Dr. Raison of the Armour Research Foundation was the project engineer. To test the flares at extreme altitude, they fitted 16 flares into the nosecone of the 2-stage SPAROAIR sounding rocket of the Sparrow missile family that could carry a 30-pound payload to an altitude of 74 miles. Modified magnesium-Teflon® flares were pretested in an altitude chamber. During a test at the Naval Missile Center, Point Mugu an aircraft at 33,000 feet altitude launched the missile that reached apogee at 392,000 feet with 57G acceleration and a 4,488 foot per second burnout velocity for a total flight time 317 seconds. The flares were ignited in pairs at 30,000-foot intervals starting at 100,000 feet altitude. Although there were equipment problems, most if not all the flares ignited as planned. Measurement of the flare radiation was unsuccessful. An alternate flare composition was also explored consisting of aluminum-tungsten trioxide with 0.5% Teflon® (added as a lubricant) that ignited at 160,000 feet and sustained combustion. The team at the Armour Research Foundation studied about 11,000 reactions in other related flare projects.

In 1961, Mr. Sarnow of the Aeronautical Systems Division (ASD) at WPAFB issued a two-year contract to the Armour Research Foundation for the study of new materials for infrared countermeasures. Dr Katz of the Armour Research Foundation was the leader of a large team of researchers. This was a study with a

very broad scope. They (1) tabulated reactions of thermodynamic significance, (2) performed experiments and made calorimetric measurements of reactive materials, (3) studied emissivity phenomena, (4) explored alkaline metal discharges of cesium and rubidium within electrical discharge tubes, (5) made a prototype of an infrared filtered flare wherein the composition was burned enclosed and the infrared radiant output was filtered, (6) considered metal reactions with fluorides and other oxidizers, (7) considered a liquid flare wherein the plume was formed by the burning slurry of particulate matter suspended in a suitable inflammable liquid substrate made with liquids such as methyl alcohol, acetone, benzene, and solids such as aluminum oxide, silicon dioxide and carbon, the latter three solids were intended to be the radiator and (8) made potassium chloride crystals for laser use.

As the work continued during 1961, the team (1) did a thermodynamic search of fluorides, phosphides, sulphides, carbides, nitrides, nitrates, borides, silicides, chlorides, oxides, peroxides, chlorates, perchlorates, chromates, dichromates, manganates, permanganates, borates, and perborates, (2) made flares of magnesium and Teflon® for comparison to binary mixes of aluminum-lead dioxide, aluminum-manganese dioxide, aluminum-cupric oxide, aluminum-cobalt(III) oxide, aluminum-tungsten oxide, aluminum-ferric oxide, magnesium-cobalt(III) oxide, and magnesium-ferric oxide, and (3) reported radiative band ratios, theoretical temperatures, and the area of the plume in square feet,

The work continued through 1962. The team acquired a Minneapolis-Honeywell high speed Visicorder chart recording system for use with the rapid scan spectrometer. This setup was used to evaluate the output of their test samples. The burning properties of seven additional oxide systems and about fifty metal-nitrate systems were selected for radiation measurement with the spectrometer to assess possible suitability for use in an infrared flare composition. The seven additional oxide systems are combinations of the metals boron, silicon, and tantalum with the oxides manganese dioxide, cupric oxide and lead dioxide. None of these systems had desirable burning characteristics. They reported that aluminum-manganese dioxide, aluminum-tungsten oxide, magnesium-cupric oxide, magnesium-manganese dioxide, titanium-cupric oxide, and titanium-manganese dioxide demonstrated uniform burning characteristics. They also reported that, as a group, binary mixtures of aluminum, zirconium, hafnium, titanium, magnesium, boron, and silicon with nitrates of lithium, sodium, potassium, calcium, strontium, silver, barium, and lead were radiometrically disappointing.

About January 1963 the survey of the theoretical thermodynamic properties of reactions was completed. The team reported that chlorates and perchlorates are much more energetic than the comparable oxide systems. Of the fuels, beryllium is the most energetic followed by uranium, hafnium, aluminum, boron, zirconium and silver. The most energetic oxidizer is magnesium perchlorate followed by lithium perchlorate, silver chlorate, sodium chlorate, and potassium perchlorate down through cesium perchlorate of the alkali metals. They examined the experimental behavior of reactions of aluminum, magnesium, titanium, and zirconium with

cobaltic fluoride, ferric fluoride, chromic fluoride, manganous fluoride, nickel fluoride and antimony fluoride. They found these reactions difficult to control and observed that the reactions exhibited low radiative output. The reaction of titanium and barium nitrate exhibited a characteristic emission at a wavelength of about 4.5μm that they associated with nitrous oxide as the source. They also stated that the radiant intensity of the nitrous oxide emission is about equal to the best magnesium-Teflon® reaction in this wavelength band region while being much less at all other wavelengths. From this they concluded that the titanium-barium nitrate reaction might offer a means for managing the spectral distribution within the radiative spectrum.

The study to identify new materials for development of infrared decoys continued at the Armour Research Foundation in 1963 by Mr. Karl Franson, Dr. Katz, Dr. Raison, Mr. Paul Ase and Mr. Robert H. Boes under sponsorship of Mr. Sarnow of the Avionics Laboratory, WPAFB. They surveyed heats of reaction of potential mixtures. They stated that oxides and fluoride systems are better than nitrates and perchlorate and that the aluminum-manganese dioxide mixture seems best for release of energy in the 2μm to 3μm and 3μm to 5μm bandpass regions on a volume basis. About 100 reactions were screened and 35 were studied in detail. Metals considered were aluminum, magnesium, titanium, zirconium, hafnium, and boron. Oxidizers considered were manganese dioxide, cupric oxide, cobaltic oxide, tetrafluoroethylene, ferric oxide, tungsten trioxide, lead dioxide, magnesium perchlorate, cobalt(III) fluoride, silver nitrate, ferric trifluoride, sodium nitrate, lead nitrate, barium nitrate, antimony(III) fluoride, and potassium nitrate.

The study to identify new materials for development of infrared decoys continued at the Armour Research Foundation in 1966 by Mr. Franson, Dr. Katz, Dr. Raison and Mr. Ase under sponsorship of Mr. Sarnow of the Avionics Laboratory, WPAFB. Zirconium-tungsten trioxide, zirconium-cobaltic oxide, zirconium-manganese dioxide, zirconium-ferric oxide, aluminum-manganese dioxide, titanium-manganese dioxide, magnesium-manganese dioxide, magnesium-cupric oxide, and magnesium-Teflon®-tungsten trioxide are some of the new reactions that they studied. The Armour Research Foundation team reported that although some of the properties were better, none is better than magnesium-Teflon®. They tried encapsulation of liquids such as toluene for use as an additive to the magnesium-Teflon® reaction. They also tried hydrocarbons, alcohols, amines, nitroparaffins, hydrazine, boranes, and liquid ammonia as fuels and nitrates, nitrogen oxides, fluorinated hydrocarbons and interhalogens as oxidizers. Some solid-liquid mixtures were considered wherein aluminum, aluminum oxide and magnesium oxide were slurried with methanol and furfuryl alcohol. Chlorine trifluoride and white fuming nitric acid slurried with nitronium perchlorate were used as oxidizers.

In a 1967 report, Dr. Raison of the Armour Research Foundation reported altitude and wind velocity studies under a contract from Lt. Richard J. Sorenson of the Penetration Aids Branch, WPAFB. Using a laboratory scale model of the RR-115 Type III decoy flare, the Armour Research Foundation team studied wind velocity

and altitude effects on flare performance. They concluded that wind velocity and altitude greatly affect the infrared radiative output and that methods must be found to reduce these effects. They also reported that burning time is largely a function of altitude. Not long thereafter, in work supported by now Capt. Sorenson of the Systems Engineering Group at WPAFB, Dr. Raison, Dr. Katz, Mr. Ase and Mr. Franson of the Armour Research Foundation conducted laboratory and flight tests of the RR-115 decoy flare. The RR-80 flare, RR-88 flare and the RR-115 flare were flight qualified and tested at Eglin Air Force Base and NOTS China Lake. Some of the flares were tested at very high altitudes. They collected relative radiative intensity versus Mach number data, which probably was the first time such information was recorded. They conducted Safety Qualification tests of the RR-115 flare at NAD Crane and added another test for parasitic ignition as a result of a Dr. Handler China Lake report in 1968 that impact from 50-caliber projectiles can ignite magnesium-Teflon®-Viton® A compositions. This had never been tried previously with the RR-115 flare. Two flares were rigidly mounted 3-inches apart. The bullet impact into the first decoy did not ignite the second parasitically. As a result of this experiment, they recommended that all future flares be designed to not ignite parasitically and concluded that the RR-115 flare is extremely safe and has excellent radiative properties both in the laboratory and in flight. In addition, they claimed to have a laboratory measurement procedure that realistically simulates the flight test environment with respect to radiative characteristics of the flare.

In the mid-1960s, Dr. Raison and Mr. Ase of the Armour Research Foundation, studied the effects of windstream on the RR-80 flare for Mr. Sarnow of WPAFB. The purpose was to develop a flare that would not be affected by windstream. They added a wire mesh shield in one case and in the other an annular shield with apertures to protect the combustion reaction from the windstream. They reported a 5-fold reduction in the radiative output at Mach 0.3 and more at higher speeds.

Under contract to the Avionics Laboratory of WPAFB in the mid 1970s, Dr. Raison, Paul K. Ase and Dr. Katz of the Armour Research Foundation conducted a high intensity flare investigation. The goal was to develop improved compositions for infrared flares for high performance aircraft operating at supersonic speeds and high altitudes. They needed more radiation in the 1.7μm to 5.5μm bandpass region. They explored additives to create hot particles in the plume. Some of the particles were carbon particles, inorganic oxides, carbonates, and solid hydrocarbons. Tests were performed at 0.6 to 2.0 Mach and at 20,000 to 60,000 feet simulated altitude. Graphite, naphthalene, sodium carbonate and anthracene improved performance substantially. They compared their requirements against the F-4 aircraft at nose and tail and with the Sidewinder 1C missile.

About 1969, Dr. Robert W. Evans, now employed by the Atlantic Research Corporation (ARC-Virginia), a division of Susquehanna Corporation, Alexandria Virginia, reported a study to learn how combustion takes place, the species generated as a gas and as a solid, and how these species emit. In this effort, Dr. Evans identified species that radiate in the infrared and their radiative strength

Some of the species studied were: hydrogen bromide, hydrogen chloride, hydrogen cyanide, hydrogen fluoride, deuterium fluoride, water, hydroxide radical, deuterated hydroxide radical, cyanide radical, cyanogen, carbon monoxide, carbon dioxide, carbon oxysulfide, nitric oxide, nitrous oxide, and ammonia. He reports that solid carbon is the emitter in the typical decoy magnesium-Teflon® flare.

Universal Match Corporation (UMC)

The Wright Air Development Center at WPAFB started a contract in 1955 with the Universal Match Corporation for research on infrared flares. At that time, Dr. Herbert Ellern was the Staff Scientist, Department of Applied Research, of the Universal Match Corporation in St. Louis Missouri. The contract objective was to develop infrared flares and measurement equipment. They wanted the flares to operate at high altitudes and Mach 1.0 with maximum radiation between 0.75μm and 3μm of the infrared wavelength region. To pursue that objective, the Universal Match Corporation loaded test compositions into M-112 photoflash cartridge cases or M-123 photoflash cartridge cases. They explored 42 different compositions with aluminum, iron, stainless steel, nickel, copper, manganese, charcoal, zirconium and silicon as fuels. The oxidant usually was potassium perchlorate, but barium chromate was also considered. They fired test flares from an A6 Lambert dispenser and used a Leeds and Northup optical pyrometer to measure temperature. Their goal was for the flare to radiate intensely in the near-infrared with minimum visibility but invisible beyond one-half mile (for covert uses). They evaluated a cool burning composition that consists of 85 parts iron powder (3μm to 5μm particle size), 10 parts potassium perchlorate, 5 parts barium chromate and about 2 parts nitrocellulose. That composition reached a temperature of about 700-800ºC. The composition ignites and burns readily at extremely low pressures even though greatly under-balanced in oxygen. They noted that a showering action achieved a greater radiating surface area and that a showering flare was desirable because of the greater surface area that was radiating.

The Universal Match Corporation team also tried a rubber based binder mixture, in parts by weight, of silicon 20 parts, Thiokol LP-2 15 parts, potassium perchlorate 9.7 parts, lead tetraoxide 55 parts, and stearic acid 0.3 parts. The main composition mixture, in parts by weight, is iron powder 83.5 parts, potassium perchlorate 9.5 parts, barium chromate 4.7 parts, vapor phase inhibitor VPI-220 0.1 parts, Sterotex® 0.25 parts and nitrocellulose 2.0 parts. Sterotex® is a fine powder prepared from food grade vegetable oil. The binder mixture is mixed with the main composition in a ratio of 1-part of the binder mixture to 6-parts of the main composition. This composition is pressed into pellets of 0.125 inches in diameter by 1.8 inches long.

Universal Match Corporation investigators also made a prototype of a Roman-Candle type flare package about 1955. These test devices were either pyrotechnically fused or initiated by electric igniters, the latter providing for the possibility of firing the pellets individually. They developed measurement

instruments for test at low temperature and up to 100,000 feet altitude. These instruments did not provide spectra. They recorded radiant energy in the range of 0.75μm to 3.0μm infrared wavelength bandpass. They also measured visible energy to determine the degree of covertness. About that time, Eastman Kodak provided information concerning lead sulfide cells. They said that cooling with ice and water to 0 °C was not necessary since chopping at 3000 hertz eliminated temperature sensitivity of the lead sulfide cells to a great extent. To enable test result comparisons with Picatinny Arsenal and Johns Hopkins Radiation Laboratory, data were presented in kilowatts per second per gram of composition.

As reported in a 1957 report, the Universal Match Corporation was engaged in an effort to reduce the weight of the Flare Ejector RR-78/ALE, believed to be the RITA flare battery dispenser, and to adjust and control the ejection velocity of flare pellets for protection of a B-47 bomber at 75,000 feet flying at Mach 2.5. To overcome ignition failures of the RITA flare, the ignition material was changed to 90 parts by weight of barium chromate, 10 parts boron, and 5 parts nitrocellulose. In addition they added silicon, infusorial earth, ground glass, and fine sand to form an ash from the burned combustion products of the ignition composition in order to retain the heat on the surface of flare composition. Even when the flare size was doubled, the radiative power of the RITA flare was insufficient to protect the B-47 bomber. Evaluation of the RITA flare, with Dr. Herbert Ellern as principal investigator, was ongoing in 1957.

Between 1956 and 1959, the Universal Match Corporation had a contract with the Wright Air Development Center of WPAFB for airborne infrared countermeasures. Originally the work was concerned with dispersal of low-visibility pyrotechnic mixtures. Even at that early date, researchers and operational personnel recognized the benefits of a low-visibility decoy. This goal later was abandoned as being too difficult to achieve adequate radiated levels of energy in the required wavelength band. The focus of the effort was changed to the adaptation of conventional white light producing flare compositions of the so-called RITA type. They reported being able to achieve high levels of infrared radiation in the desired spectral regions from compressed cylindrical pellets burning on all surfaces. Additional objectives were to develop showering type, low intensity, and flares that radiated in the long wavelength region. They experienced operational problems of ejecting substantial numbers of these pellets and sequentially igniting them under flight conditions from B-47 bombers at altitudes to 45,000 feet.

Next, the effort was directed toward the development of flare compositions of a new type that produced considerably higher levels of infrared radiation. The intent was to use the improved composition to replace the illuminating composition in the RITA flare. Operational problems continued. To overcome these deficiencies, they initiated general and theoretical studies to understand the reaction mechanisms of conventional metal-oxidizer combinations of various stoichiometries. One approach was to replace the magnesium with another fuel but continuing with sodium nitrate as the oxidizer. They considered fuels like aluminum, boron, beryllium, carbon

chromium, iron, magnesium, molybdenum, silicon, thorium, titanium, tungsten and zirconium. They computed the major thermodynamic properties of these reactions. They repeated the experiment with lithium nitrate as the oxidizer in place of the sodium nitrate. Many of the candidate fuels were ruled out for reasons of toxicity, safety, and practicality. The study was narrowed to aluminum, magnesium, and zirconium as the fuels and sodium and lithium nitrates as the oxidizer, and in some instances, they used both magnesium and aluminum in the same formula. These fuel/oxidizer combinations were also evaluated by calorimetry.

As an alternate manufacturing process, the Universal Match Corporation explored casting the RITA composition using various binders as the casting agent. These compositions also did not produce sufficient radiation. Next they considered casting thermite type compositions. One shape was spherical with internal burning to produce sufficient pressure for combustion propagation and with holes on the exterior surface to allow the combustion products to exit. One should note that the Universal Match Corporation team already had been considering the Balls-of-Fire concept that has many similarities to this approach. This approach also fell short of the desired infrared output. About 1956, news and information about the high infrared output of magnesium-halogenated hydrocarbon compositions was propagating rapidly throughout the flare industry. With this information, the Universal Match Corporation team chose to abandon the cast composition investigations and to continue development using the new magnesium-halogenated hydrocarbon compositions technology.

The Universal Match Corporation team reported the RITA flare excelled in only the visible portion of the spectrum. Instead of the illuminating composition, they next explored magnesium, Teflon® and Kel-F® wax as the main composition that they reported to be better than the RITA output. A magnesium-Teflon® composition, named FLORA, was reported to be 18 times better in the 2μm to 3μm bandpass region and five times better in the 3μm to 5μm bandpass region as compared to the magnesium-sodium nitrate composition in the RITA flare.

Continuing in 1958, the Universal Match Corporation team reported that FLORA flares with a composition consisting of 54% magnesium (22μm particle size) and 46% Teflon®-7X had a tendency to snuff out at high altitude. They added titanium in one case and boron/barium chromate in the second case to facilitate combustion. FLORA Type B composition consists of 42% magnesium, 49.2% Teflon® and 8.8% boron-barium chromate mixture. FLORA Type C composition consists of 39.9% magnesium, 46.8% Teflon® and 13.3% boron-barium chromate mixture. A 60% magnesium-40% Teflon® composition worked well as did the one with 8.8% boron/barium chromate added to the mixture. The latter is a mixture of 16% boron with 84% barium chromate. The FLORA flares are cylindrical, weigh about 3.4 pounds (1545 grams), occupy 54.75 cubic inches and have an 80.22 square inch surface area. Burning is over the entire surface.

Another approach is to paint the external flare surfaces with a 16% boron - 84% barium chromate mixture to facilitate burning at high altitude and high ejection speed. Substitution of calcium chromate for barium chromate that releases much more energy was also considered. To facilitate combustion when loaded into an RR-77 flare assembly, they added titanium in the one case and the boron-barium chromate mixture in the other case. Both the titanium and the boron-barium chromate mixture when added to the magnesium/Teflon® mixture radiated substantially more than did the RITA-1A flare when tested at 50,000 feet altitude. Flares with the mixture of 8.8% boron-barium chromate added to a 60% magnesium-40% Teflon® mixture were reported to burn 4.8 seconds, which was considered too fast. To obtain additional data about the experimental units, ten different flares that would fit the RR-77 flare assembly block were developed that were sent to Aerojet-General for simulated altitude and wind-tunnel tests using the vacuum chamber facilities there.

To achieve the infrared output required for protection of aircraft with very large radiative signatures, a program was started at the Universal Match Corporation for development of a high-energy producing device. A requirement was set for 20 kW/sr in the 1.8μm to 2.8μm bandpass region and 35 kW/sr in the 3.0μm to 5.5μm bandpass region. The flare size had to be such that a minimum of four devices would fit into an RR-77 flare assembly block of the AN/ALE-14 dispenser system. They prepared cylindrically shaped pellets of 4.375 inches in diameter by 3.5 inches long. The pellets weigh about 3.3 pounds (1500 grams). Their surface area was about 80.2 square inches, the entire surface area of which would be ignited at one time. Two pellets were placed into each of the two five-inch diameter flare ejector tubes of the flare assembly block. After one such set-up was fired successfully, a second was sent to the Wright Air Development Center at WPAFB for further testing.

On 19 September 1958, Universal Match Corporation put a 1000 cubic foot vacuum chamber into operation to support the decoy flare research. It could be evacuated to 500 μm of mercury and could simulate 100,000-foot altitude.

Great Britain (UK)

In the late 1950s, Wallop Industries Ltd. received a contract from the Royal Armament Research and Development Establishment (RARDE) Langhurst Horsham West Sussex UK to develop tracking flares. These contained illuminating composition, an example of which is SR-568A made from 55 parts magnesium, 4 parts lithographic varnish and 41 parts sodium nitrate. This is the formula utilized in flare number 2. The number 2 flare is called FIRESTREAK, the number 3 flare is called SEASLUG, the number 4 flare is called RED DARTER, and the number 5 flare is called RED SHOES. The flares are different in length and contain illumination composition variants.

Infrared decoy flare development spread quickly to the UK from the USA. In September 1957, Mr. T. S. Moss, Mr. D. R. Brown, Mr. T. D. F. Hawkins of the Royal Aircraft Establishment (RAE) Farnborough, Hants England evaluated three compositions for possible use as an infrared decoy. These were: SR-580, SR-107 and Cordite Type SC.

a. SR-580, an illuminating formula, is 60% magnesium and 36% sodium nitrate, and 4% acaroid resin.

b. SR-107 is 35% magnesium and 65% ferric oxide.

c. Cordite SC is 49.5% nitrocellulose, 41.5% nitroglycerine, and 9% carbamite. Synonyms for carbamite are: 1,3-diethyl-1,3-diphenylurea, bis(N-ethyl-N-phenyl)urea, N,N'-diethyl-N,N'-diphenylurea, centralite, and ethyl centralite.

The materials were evaluated in the wavelength bands in which lead-sulfide and lead-telluride are sensitive. Although the cordite spectrum showed a strong emission in the region of the red spike (carbon dioxide emission region), the RAE team speculated that this material would not radiate sufficiently at high altitude. Their recommendation was that RARDE Langhurst should continue studying selective emitters and to exploit Kel-F® material, which was reported in America to be a very efficient decoy material with a low burning temperature of about 1700 °C.

About 1959, Mr. Brown, Mr. J. P. Chamberlain, Mr. N. D. P. Hughes and Mrs. Shirley Jenkins of the Royal Aircraft Establishment Farnborough, installed a radiometer spectrometer inside a 1959 Hawker Siddley Comet 2E aircraft. The spectrometer line-of-sight was through the side of the fuselage. Pressurization was maintained inside the cabin. The gear was capable up to 14,000 meters altitude. They made measurements in the infrared 2µm to 5µm bandpass region. Simultaneous clusters of magnesium-sodium nitrate illumination flares showed that the infrared output was proportional to the flame area and that the infrared emission more than doubled by increasing from four flares to six flares in a cluster.

Mr. Hughes, Mrs. Jenkins and Mr. Brown of the Royal Aircraft Establishment Farnborough conducted airborne emission measurements of infrared decoy flares in 1962. Radiometers operating in the 2μm to 3μm and 3μm to 5μm bandpass regions were installed in a Royal Air Force (RAF) De Havilland Comet-2 XN453 aircraft. The radiometer could be operated while the inside of the instrument was pressurized. The instrument was capable of operation up to 14,000 meters (45,934 feet) altitude.

RARDE Langhurst made the prototype flares for the experiment. The infrared flares were intended to protect “V” bombers. The term “V” bomber was used for RAF aircraft during the 1950s and 1960s that comprised the UK’s strategic force, namely the Vickers Valiant, the Handley Page Victor and the Avro Vulcan. The flare decoy units identified as Flare Type E/2/1, later to become the UK Mk 1 Decoy about March 1963, were 2.25 inches in diameter by 5.3 inches long. The units contained a safe and arming device (S&A). The grain contained 55% magnesium and 45% Teflon® with longitudinal grooves around the grain circumference and produced a rise time to peak intensity of 0.5 seconds. The radiative output of these decoys was measured at 1,000, 10,000, and 40,000 feet altitude. They concluded they needed to drop pairs at low altitude and quadruples at high altitude.

Mr. Jackie Roberts, about 1963, fabricated an infrared spectrometer for the Vulcan aircraft.

COMPOSITION CHARACTERIZATION and CONCEPT DEVELOPMENT

Forward Launched Decoy

The Forward Launched Decoy (FLD) concept was first noted during the Balls of Fire project about 1958. During a decoy trajectory study for the Aeronautical Systems Division of WPAFB, Mr. J. H. Henson of the University of Texas revived the concept in 1961. Mr. Henson's objective was to convert the AN/ALE-9 chaff rocket, developed by the Defense Research Laboratory in 1954-1959, to forward launch an infrared decoy flare. He replaced the chaff with cylindrical pellets pressed with a 60% magnesium- 40% Teflon® composition. The combustion products from the flare were exhausted through ports in the head of the device. Universal Match Corporation and the Armour Research Foundation provided flare pellets for this project.

As follow-on to this work, in early 1960, Mr. Sarnow of WPAFB sponsored the development of the RR-96(XY-1)/Al infrared countermeasures rocket flare at the Armour Research Foundation of the Illinois Institute of Technology, the principal investigators being Dr. Raison and Dr. Katz. The assembly contains an RR-80 flare. The rocket is 43 inches long by 2.75 inches in diameter and weighs a total of 12.9 pounds. The rocket is dispensed from an ALE-9 type dispenser system from B-47 and B-52 aircraft. They conducted sled tests at Edwards Air Force Base, safety tests at NAD Crane and flight tests at Eglin Air Force Base. When subjected to a 1000 feet per second velocity during a 12 second static burn, the Armour Research Foundation team reported that the radiation in the lead sulfide and lead telluride bands had enough energy to serve as a countermeasure to protect B-47 and B-52 aircraft.

About 1960, Mr. R. Stern of the American Machine & Foundry Company, Niles, Illinois, under a contract with the Wright Air Development Center of WPAFB worked on a concept for a forced trajectory decoy rocket. Mr. Stern evaluated parameters such as the trajectory needed by the decoy to defeat the threat, control, propulsion and stability requirements. This may have been a follow-on project to the study by Dr. Katz of the Armour Research Foundation at the Illinois Institute of Technology in 1958 of the concept of using the Balls of Fire in a forward launched device, especially to protect bombers.

Mr. Knapp and Mr. Arthur Graff of the Research Laboratories at Picatinny Arsenal continued forward launched decoy flare development efforts under sponsorship of Mr. Francis Linton of the Avionics Laboratory at WPAFB as described in a 1964 report. The objective is to determine feasibility of using pyrotechnic flares to simulate the total radiation characteristics of various rockets such as the High Velocity Aircraft Rocket (HVAR) in the 2μm to 5μm spectral bandpass region. They wanted a forward launched infrared decoy for supersonic vehicles such as the B-70

bomber. Rocket propelled flares appeared feasible using a magnesium-Teflon® composition. They needed very high radiant output from the flare for 20 seconds at 70,000-foot altitude. The Picatinny Arsenal team formulated an ignition composition FW-210 consisting of manganese dioxide and zirconium that is effective at high and low altitudes and they performed wind tunnel and altitude chamber tests to support their investigations. The perforated-can flare concept (related to the shielded flare concept) was also considered for incorporation into a forward launched decoy flare design.

Between 1963 and 1965, Mr. Henson, Mr. J. Worden, and Mr. Richard T. Balzen of Tracor, Austin Texas developed the XADR-9A countermeasures rocket. Mr. Eugene E. Hawthorne and Mr. B. W. Putriment of the Air Proving Ground Center, Eglin Air Force Base tested the flare portion of the XADR-9A countermeasures rocket in 1967. The Eglin team also wanted to develop a decoy flare fired forward by a rocket. They observed a loss of radiative power during operational tests and noted that the smoke trail caused significant obscuration, dependant on the observation angle.

Roman Candle Flare (RC)

As early as 1972, the Grumman Aircraft Company received a contract for development of a hydrocarbon fuel infrared decoy also known as the “Roman Candle” (RC) decoy flare. This development is based upon using a flexible shaft such as used in pole-vaulting to hold the decoy or a scaled up weed-burner from 15 to 17 feet below an HH-1K helicopter. The contract evolved into the joint service project reported in 1973. Mr. Breslow of China Lake and Mr. Schivley of WPAFB directed the project whose goal is to investigate and demonstrate the use of on-board fuel from the aircraft to generate infrared decoys. This includes investigation of rapid gelling, gelling additives, the quantity necessary, decoy size, burning duration, ejection velocity, spectrum matching to the aircraft, and rapid cycling of ejection. Both Air Force JP-4 fuel and Navy JP-5 fuel were considered. They reported several observations, these being: (1) the efficiency of Navy JP-5 fuel is higher than that of Air Force JP-4 fuel, (2) the efficiency of both fuels is better in the 3μm to 5μm bandpass region than in the 2μm to 3μm bandpass region, and (3) efficiency increases with decoy weight (size) as does burning duration.

The airborne evaluation of the Roman Candle system using a demonstration model was conducted on a UH-1N helicopter. The concept is applicable to either the preemptive or the reactive mode of countermeasures. The demonstration model weighs 42 pounds and contains 100 decoys. Feasibility was demonstrated. In follow-on flight tests, Roman Candle fireballs were deployed from an A-4 aircraft at 150 to 435 knots and at 3,500 to 20,000 feet altitude. Success was achieved at 435 knots and 7,000 feet altitude or lower and at 200 knots at 20,000 feet altitude. As a further option, they could fire 12 single prepackaged Roman Candle shots from a LAU-61/A Launcher. Later four live fire shots were conducted. The target aircraft was the NA4-E and the chase plane was the NRA-3E equipped with an AIM-9G

Sidewinder surrogate for a threat missile. The test was conducted at 300-345 knots and 3,500 feet altitude.

Airborne infrared measurements of the Roman Candle flare were made during a flight test on 26 August 1977. Mr. Charles. L. Godwin of the Pacific Missile Test Center (PMTC), Point Mugu California conducted the test. Radiometric and spectral measurements were made with the Airborne Turret Infrared Measurement System (ATIMS) and High Speed Instrumentation Pod (HISIP) pods. The burning duration of the Roman Candle flares was too short. The spectra showed a near graybody distribution of radiation, which suggests incomplete combustion and the formation of soot as the emitter. The Mk 46 Mod 1A flare was used as a reference.

Balls of Fire Decoy (BOF)

On October 25, 1954, Mr. J. L. Hult of the RAND Corporation, Santa Monica California reported the results of their study of infrared countermeasures for the Air Force. This comprehensive study outlined the threats posed, tactics and countermeasure requirements. They considered mechanical and system needs and radiation characteristics, thermodynamics and chemistry of proposed sources. They also considered mixed and multiple expendables, smoke puffs, towed sources, and infrared blinkers. A significant result of this study was the recommendation for a decoy flare concept named the Balls of Fire (BOF). They identified the parametrics of the problem, listed the physical properties of the reaction constituents that included mixtures of aluminum with iron oxide or molybdenum oxide or tungsten oxide.

The Air Force contracted with the Armour Research Foundation to develop the Balls of Fire concept as an infrared decoy to protect B-47, B-52 and B-58 bomber aircraft from infrared missile threats in the 1.8μm to 2.8μm (lead sulfide) bandpass region. Dr. Katz and Dr. Elliott Raisen of the Armour Research Foundation were the principal investigators. Other contributors were Mr. Ase, Mr. Franson, Mr. F. Child, Mr. W.F. Christian, Mr. A.G. Lane, Mr. H. Olson, Mr. J. Pito and Mr. R. Spaulding. The project lasted from about 1956 to 1958. Their concept was to make a four-inch diameter shell containing a thermite composition such as aluminum-tungsten oxide. These burning spherical shells would be dispensed from aircraft to serve as an infrared decoy. Some additional concepts for this device were: an enclosed reaction, a fusible shell, an intumescing shell, a reaction with ejection of combustion products through ports in the shell (perforated-can concept), and impinging flames.

Early Balls of Fire shells were made from graphite, copper or iron. Molybdenum and tantalum shells were also considered. Due to shell ruptures during test, the developmental focus was directed toward shell material, shell wall thickness, thermite charge composition, and insulation evaluations. Additional options for reducing agents in the thermite charge that they considered were aluminum, beryllium, chromium, magnesium, Teflon®, lanthanum, hafnium, scandium, zirconium, lutetium and yttrium. Some oxidizer choices for the thermite were

molybdenum oxide, ferric oxide, nitrogen tetraoxide, tetrafluoroethylene, and various nitrates.

In that time period, it was thought improbable that pursuit missiles would home on the exhaust of a B-58 bomber cruising at Mach 2 presumably because the threat would not being able to catch up to the target. As a result of the perceived threat capability, about 1958, Dr. Katz of the Armour Research Foundation proposed the concept of using the Balls of Fire in a forward launched device especially for protection of B-58 bombers. Protection of B-47 and B-52 bombers was also under consideration.

Theoretical calculations by the Armour Research Foundation team suggested that hafnium, scandium, yttrium or lutetium should yield superior systems. The aluminum-tungsten oxide and aluminum-iron III oxide thermites functioned satisfactorily at 75,000 feet simulated altitude. The aluminum-tungsten oxide composition ignites at 840 °C, which is 200 °C above the melting point of aluminum suggesting a liquid-solid reaction. Other formulae did not propagate but did so upon addition of tantalum ribbon or potassium dichromate. Additional developmental tasks included study of accelerators, diluters, and retarders for the aluminum-tungsten oxide formulation. The investigators also planned studies of heats of reaction, burning rates, high altitude effects, and alternative reactions.

A 2-mm thick graphite shell which had 38 seven-sixteenth holes distributed over the sphere surface was tested. During the burn, incandescent particles were ejected through the holes to form a cloud. The spouting of these particles resulted in the device being labeled a "spoutnik". Perhaps this is a play on the word Sputnik, it having been launched on October 4, 1957. The plan was to launch these decoys in a forward direction suggesting that even at that early date, dispenser location and ejection direction were known to be important factors for defeating some threats.

Another concept, the transient shell system, is a variant of the above graphite shell. Instead, the Armour Research Foundation team used a phenolic shell that would burn away during the functioning of the device. They note that the shell is necessary to prevent dispersion of the reaction products, but after the gasses have vented, the shell is no longer needed. Removal of the shell exposes the infrared radiator, that being an incandescent coherent sphere clinker of tungsten sponge resulting from the burning aluminum-tungsten oxide thermite.

The Armour Research Foundation researchers lacked radiation measurement equipment in the 1958 timeframe. They tried to use the Barnes radiometer at the Universal Match Corporation's test location in Saint Louis Missouri. It did not have sufficient capability and would overload during test. The researchers then obtained a radiometer with a lead sulfide cell and filter from Johns Hopkins University. Radiometric performance and combustion temperature were measured, the latter between 2000 K and 3000 K.

The Balls of Fire concept was revived about 1961 during the development of the RR-88(XY-1)ALE Flare for the B-52 bomber. The dispenser concept contains two ejection tubes. Each tube has two BOF flares encapsulated with polyurethane foam in a metal capsule. Each Balls of Fire flare, which is compatible with the B-52 AN/ALE-14 Ejector System, is ejected individually downward at 65 to 150 feet per second. The flare burns for about 10 seconds with a temperature of 2200 K to 3000 K. The composition in these Balls of Fire flares is a mixture of 22.5% aluminum, 76.5% tungsten oxide and 1% Teflon®. The ignition composition is a mixture of 57% barium chromate, 38% zirconium, and 5% nitrocellulose.

The Balls of Fire decoy flare development ultimately was not adopted, however the concept was to be revived again about 1966 using improved materials. An expanded discussion of the Balls of Fire project may be found in *Electronic Countermeasures*, in Chapter 22 written by Dr. Marshall D. Earle.[10]

RITA-FLORA Flare Developments

The RITA-FLORA flares make up a family of flares developed by Picatinny Arsenal for the Air Force for protection of the B-52 bomber. Their contents evolved from an illuminating composition to one that radiates in the infrared. The RITA-FLORA developmental evolutions lead to the development of the ALA-17 MTV flare.

At the request of the Air Force, Mr. Stanley Resnick, Mr. Gary Weingarten, Mr. Knapp, Mr. Leo Frey and Mr. Jesse Tyroler of Picatinny Arsenal started development of a RITA flare in October 1954. The flares were to be dispensed from a Lambert A-6 Ejector that was designed to dispense M-112 photoflash cartridges these being 1.57 inches in diameter by 7.73 inches long. The burning time was to be 3 seconds while radiating intensely in the 0.8µm to 2.5µm bandpass region. The composition in the RITA flare, in parts by weight, is 70 parts magnesium, 30 parts sodium nitrate and 5 parts Laminac® 4116 (a polyester binder). It burns 4.5 seconds statically and 2.5 seconds dynamically when ejected at 50 to 100 feet per second. There were problems with the black powder expelling charge. A composition, in parts by weight, of 10 parts boron, 90 parts barium chromate and 5 parts nitrocellulose was added for ignition of the first fire. 1000 units were delivered to the Air Force by May 1955.

Mini-Flare Development

In November 1967, Picatinny Arsenal was requested by the Electronics Command at Fort Monmouth to develop a mini-flare for a dispenser, which the Electronics Command had developed. The nomenclature assigned is believed to be the XM-126 dispenser. The dispenser designed for the UH-1D helicopter carries 154 mini-flares. There are two dispensers per aircraft. The flare is 1-inch in diameter by 2.75

[10] Electronic Countermeasures, Peninsula Publishing, Los Altos California, 1978, ISBN 0-932146-00-7.

inches long and weighs 0.16 pounds. The Navy wanted to adapt this flare to their helicopters and FAC aircraft but the Army developed flare was not bore-safe. A feature of the dispenser design is that if a flare does not ignite, photodiodes in the dispenser will cause another flare to be fired immediately. The Navy at China Lake undertook the task to develop a bore-safe device. In addition, China Lake proposed two alternate concepts. One is a towed decoy and the other is a smoke/flame blob. It was anticipated that a suitable towed flare could be produced that would provide on/off capability and long duration. The system would consist of appropriate cockpit controls, fuel supply of the aircraft, fuel line to the flare burner, the burner and flight control units. Such a system would be inexpensive when compared to a flare dispenser and multiple flares. The system would not require ignition until needed. The second approach consists of expelling either a flaming blob or alternatively an absorbing cloud from the aircraft. This approach also offers the advantages of utilizing the aircraft's existing fuel supply. Both require a pumping or ejection system and ignition source. The ignition source could be excluded if the primary fuel is mixed with a small amount of pyrophoric material, which would cause the combined mix to burn when introduced into the atmosphere. These concepts no doubt are the precursor to the Roman Candle flare development. The concepts were expanded to provide an independent feed control of pyrotechnic powders to provide additional degrees of freedom of burning rate, fuel to oxidizer ratio, variable intensity with altitude, on/off, and restart. Solids considered were magnesium-Teflon® and magnesium- sodium nitrate.

In a 1971 report, China Lake noted that it successfully made a bore-safe design for the mini-flare dispenser and was evaluating the dispenser for Navy helicopters and FAC aircraft. The ignition system was adapted from the EX 49 Mod 0 decoy flare. The expelling charge was replaced by a Mk 2 Mod 0 ignition element that when fired initiates a pellet of ignition mix CT-144, which had been placed in the piston cap. The bore-safe mini-flare grain consists of composition PL 6320. The grain is 1.88 inches long by 0.94 inches in diameter and weighs 0.066 pounds.

In 1970 Mr. Breymaier headed up a team at the Willow Run Laboratories of the University of Michigan to evaluate mini-flares for low speed aircraft against ground-launched infrared seeking missiles, one of which is the Chaparral 1C missile. The team studied launch zones, flare trajectories, aircraft speeds and flare rise-times. Mr. Knapp was part of a team at Picatinny Arsenal that developed the mini-flares in several configurations. The flare is 1-inch in diameter by 2.75 inches long and weighs 0.16 pounds. By 1972, the Picatinny Arsenal team reported that a small, high-energy, rapid ignition flare had been developed to provide protection for the AH-1, UH-1, OH-58 and OH-6 rotary wing aircraft against ground-launched missiles such as the Redeye, Sidewinder and Chaparral missiles. The Picatinny Arsenal team tested flare compositions under various wind conditions. They added nitrocellulose, anthracene, Viton® A, Viton® B, manganese dioxide, zirconium, molybdenum trioxide and chromium trioxide to the magnesium-Teflon® basic composition. The flight tests were at China Lake sponsored by the Electronics Command at Fort Monmouth. The Army Missile Command Redstone made

dynamic measurements of the Mk 46 Mod 1 flare and the XM-196 mini-flare. The drop altitude was 1,500 feet. The flare radiant intensity was measured from the ground. The mini-flare had a good rise time in a 100-knot air stream but burned less than 3 seconds. The Mk 46 Mod 1 flare also had a good rise time but did not sustain intensity. At 400 knots, the Mk 46 Mod 1 flare had a very poor rise time. The altitude was 5800 feet for the latter test.

Flare and Decoy Developments and Improvements

This section shows a number of tasks in approximate chronological order. The descriptions are intended to show that improvement of the decoy flare is a continuous process, that many tasks are ongoing at one time, and that many activities are simultaneously involved in this effort. There always is the need to make the product perform better, to redesign the product to make the device safer or less hazardous or just to incorporate a new feature because the threat that it has to defeat has changed. This section is also intended to describe new and different technology as it is applied to devices undergoing development or product improvement.

The need for infrared decoys was not limited to the U. S. Navy. The U. S. Air Force, U. S. Army, and Great Britain initiated studies and developments as soon as the infrared missile threat appeared. Others worldwide immediately started their own programs. One example of this is the infrared countermeasures study under contract to the Air Force, reported in 1953, by researchers of Haller, Raymond and Brown-Singer Inc., State College, Pennsylvania. The concern was protection of bombers at high altitude. They concluded the two most promising methods to protect bombers were decoys and signature reduction. Their study included pyrotechnic agents, chemical smoke, radiant particles, ejected decoys including multiples and towed decoys. Cooling and shielding were considered for aircraft signature reduction.

From January 1949 to January 1960, Del Mar Laboratories, Santa Monica, California conducted research on an infrared aerial towed decoy system. They used a ram-air turbine and an alternator to provide an electrically heated infrared source in the towed vehicle that radiated through a Pyrex® dome (transmission is about 0.3μm to 2.5μm) that passes infrared radiation in the lead sulfide wavelength bandpass. In 1956, Del Mar made three flyable towed systems for towing behind high-speed bombers. These were tested successfully. In 1958, two infrared towed targets were flight tested at the Naval Air Test Center, Patuxent River, Maryland: one from Del Mar Engineering Laboratories and the other from the Colonial Aircraft Corporation. The target that was stable in flight while being towed had four tail fins and rotated at 1000 rpm. Four tubes adjacent to the fins housed unidentified flares. The target was designated CT-2 target and is similar to the Aero 36 target. The CT-2 target spins at 4-times the rate of the Aero 36 target and weighs 49 pounds as compared to 19 pounds for the Aero 36 target. The Colonial Aircraft Corporation

unit, while undergoing test at 250 knots, spun at a high rate and completely disintegrated.

From 1954 to 1956, Dr. Earle while employed at the Johns Hopkins University, Carlyle Barton Laboratory (Radiation Laboratory) conducted research for the Air Force in the areas of infrared decoys, infrared properties of smokes and fogs and the description of infrared target seekers. He measured infrared flares made by Kilgore, then in Westerville Ohio and one flare from Unexcelled Chemical Company of Cranbury, New Jersey. The Kilgore flare named type DF contained potassium nitrate, charcoal and rosin. A variant contained silicates that were added to the DF mixture. Other variants were magnesium, strontium nitrate, potassium perchlorate, sulfur, potassium nitrate, lithium carbonate, and charcoal added to the DF mixture. Dr. Earle noted that flare compositions containing charcoal have the lowest energy content. He also considered reflective decoys such as smoke puffs to scatter light and suggested a gelled hydrocarbon such as napalm with an oxidant. As follow-on, he gelled gasoline, kerosene, benzene, toluene and xylene. The gasoline and kerosene gels yielded enhanced carbon dioxide emission. He noted that fire clay and silicon carbide additives did little to alter the infrared spectrum and concluded that reflective decoys would be of little use. Nevertheless, smokes, fogs and low-density plastics were considered for their ability to obscure or reduce the radiative signature of aircraft. Dr. Earle also proposed an infrared-radar decoy that lasted 15 minutes and would emit radiant energy one-quarter of that of the B-47 bomber. The radar part would be an aluminum coat on a Mylar parachute. He also discussed the features of a low-temperature infrared decoy and a towed decoy. In his analysis of flare burning time and aircraft protection, he makes the statement that a countermeasure source burning time of 8 to 12 seconds at an intensity, which is dominant over the aircraft, seems adequate.

Mr. J. B. Newman at Johns Hopkins University conducted a study for the Air Force in 1955 concerning pyrotechnic decoys for use as infrared countermeasures. The primary aircraft of concern was the B-47 bomber. The possible missile threats were the Sidewinder, infrared Falcon, Aerowolf, and the British Bluejay, all with lead sulfide detectors. Mr. Newman’s team consulted with the Pyrotechnics Group at NOL White Oak, the Infrared Section of Squier Laboratory of the Signal Corps, the Night Photo Laboratory of WPAFB, the Armaments Laboratory of WPAFB and Picatinny Arsenal. Fifteen different types of flares were tested. Six were from Aerial Products, Elkton, Maryland. Four conventional military flares were from Unexcelled Chemical Corp. and three were from Kilgore Corp. The M8A1 and the M26A1 are aircraft parachute flares, the M50 is a tow target flare and the M76 is an airport flare. They took spectra with a Perkin Elmer Model 99 monochrometer using a thermocouple detector. The Leeds and Northup thermocouple served as a total radiation monitor. Early spectral data were taken at Camp Wometo in Bel Air, Maryland and later spectral data were taken at Edwards Air Force Base, California. The Kilgore K2 flare was declared to be the best of the lot.

In a related effort, researchers at the Johns Hopkins University Radiation Laboratory in the 1956 time period were tasked, as a first priority, to obtain radiation characteristics of targets and decoys. Their second priority was to develop attenuating media. About 1960, Ms. Betty Lou Raskin of the Radiation Laboratory with the advice of Dr. Earle, conducted a study for the Air Force to propose new infrared compositions. The study was prompted by the need for more efficient flares to protect supersonic aircraft that would be developed subsequent to the B-47 bomber and the B-52 bomber. They recognized that the spectral and spatial distributions of the radiation emitted by future aircraft would be different from existing ones. They anticipated that future aircraft would emit much larger amounts of thermal radiation from the engine exhausts and also would radiate due to aerodynamic heating of the aircraft surfaces. The new compositions would need to perform effectively at 70,000 feet altitude where the atmospheric pressure is only about 0.04 times its sea level value and the oxygen content approaches zero. Noting that the FLORA type flare containing mainly magnesium and Teflon®, was a better source of infrared radiation than other types of flares, they set out to explore the reactions of 13 different metals with 17 different highly fluorinated, chlorinated, and oxygenated organic compounds. The Johns Hopkins University team noted that fluorine is the most powerful oxidizing agent and consequently that fluorine atoms should be the sole oxidant present in an infrared flare. They also reported that magnesium was the most practical metal found to be present most often in reactions with the highest theoretical thermal outputs.

The Hayes Corporation, Birmingham, Alabama initiated infrared countermeasures and radiation suppression studies in 1955. During that timeframe it already was apparent that a very strong aircraft infrared signature made it very difficult for decoys to seduce the infrared threat missile from the target aircraft.

There was a need about 1957 to create a decoy device that would simulate the signature of a turbojet engine. Instead of the pyrotechnic decoy flare approach, Northrop Aircraft, Inc., Hawthorne, Nevada proposed an inflatable envelope that absorbs the energy from a self-contained pyrotechnic and re-radiates this energy at a lower temperature approximating that of the heated surfaces of the turbojet engine. Use of an inflatable envelope permits the decoy to occupy only a small volume before being ejected. The low total radiation per unit area of surface dictates the use of a decoy with a large surface area. By use of a large inhibited flare with a long burning time, the inflated envelope decoy could be used as a free or towed target. The resultant decoy would be a large-area extended-source with a low effective temperature.

In a 1957 report, Mr. A. L. Pittinger describes an attempt to make a low-gas tracking flare utilizing an unspecified metal-metal oxide thermite reaction to put inside the Pogo-Hi Rocket nose cone. The reaction releases about 75 joules/gram of energy in the lead-sulfide sensor band region and lasts for 120 seconds. In June 1956 the Cooper Development Corporation (CDC), Monrovia California prepared the first units, the CDC Model 155 infrared emitter. The final model was placed in the Pogo-

Hi rocket target. When the rocket reaches altitude at 60,000 feet, a parachute deploys, the ignited thermite melts the magnesium nose cone that exposes the infrared radiator used to attract a test missile. Radiative output at altitude is about 25% of that at sea level. Another variant was fitted to an F6F-5K drone aircraft with six emitters, two on each wing tip and two on the tail.

Researchers at Ohio State University, during 1955-1956, under contract from the Rome Air Development Center, Griffiss Air Force Base studied infrared emission from flames of methane-air, methane-air with chlorine added, methane-air with a Welsbach mantle added, propane-air, oxygen-acetylene, hydrogen-chlorine, ammonia-oxygen, carbon monoxide-oxygen, methane-nitrous oxide-hydrogen, carbon monoxide-oxygen-sulfur hexafluoride, carbon monoxide-air-Freon 13, and carbon monoxide-air-boron trifluoride. They also studied fuel-air flames with gasoline, paraffin, benzene, aniline, methanol, ethanol, ethyl ether, carbon disulfide and hydrogen as fuels. They attempted to determine the identity of the radiating species, the brightness temperature of the flame and the flame thickness.

In 1956 the Hallicrafters Company, Chicago reported development of flare dispensing equipment under an Air Force contract. They referred to a loaded dispenser case full of flares as a flare battery. The concept is to replace an entire empty or partially filled flare battery with a flare battery containing a full load of flares. The flare battery with a full flare load weighs about 100 pounds. The flare battery has outside dimensions of 6.5 inches by 13 inches by 13 inches. The dispenser case or block has 17 cylindrical cavities, 1.875 inches inside diameter by 20 inches deep. Five flares are placed into each cavity. Provision through the side of the cylinder at five locations along the cylinder length is made for a squib to ignite each individual flare. The dispenser setup can fire each flare at intervals of 0.7 to 10 seconds. There are 85 circuits from the flare battery to the dispenser controller.

Five 2-inch long jacketed-variant RITA Flares, housed in a perforated steel jacket, are placed in each cylinder of the flare battery making a full load of 85 flares. The perforated case design suggests similarity to the Balls of Fire or perforated can design described elsewhere wherein the flame spews simultaneously from all the holes in the surface of the flare case. Besides the RITA flare, additional flares were tested at 50,000 feet and at Mach 0.85 using the flare battery dispenser. The 3-second version is called RITA 3-second variant and a 5-second version is called RITA 5-second variant, both provided by Picatinny Arsenal. Universal Match Corporation provided the UMC-ASC129 flare modified for high altitude and a UMC pelleted flare. Mentioned in 1956 report.

An early 1958 concept was presented to Mr. Francis Linton of WPAFB by Lambert Engineering Company Saint Louis, Missouri for a number of different flare assemblies to improve the RR-77 AN/ALE-14 flare assembly. The RR-77 flare assembly housing fits into the AN/ALE-14 ejector system installed in bomber aircraft. Lambert Engineering offered variations in the number of tubes and the number of flares in each tube. The M-112 photoflash cartridge case was used as

the test vehicle. The flares in the cartridge are ejected sequentially. RITA flare technology utilizing infrared compositions was used for this development.

It was reported in 1959 that Mr. Eugene E. Elzufon of the US Flare Division of the Atlantic Research Corporation had a contract to conduct infrared experiments. He performed controlled burning studies, explored thermodynamics and chemistry of the reactions and conducted high altitude (70,000 feet) burning rate and pressure studies. He also attempted to find binders to replace Kel-F® wax. At that time, the ignition composition was a mixture of 10% boron and 90% barium chromate. The composition ingredients were mixed in a muller and pressed at 400-500 psi. The W137 tracking flare most likely resulted from this work.

Under the direction of Mr. N. C. Eckert, Head of the Research and Development at the US Flare Division of the Atlantic Research Corporation, Mr. H. E. Curtis and Mr. D. D. Parish received funding about 1960 from Detachment 4, Wright Air Development Division of Eglin Air Force Base to develop a long wavelength flare with increased emission in the 3μm to 5μm bandpass region. The researchers primarily investigated fuel and oxidizer additives to the magnesium-Teflon® system. The additives included silicon, anthracene and lithium perchlorate as emitters or as radiation enhancers. As agents to minimize altitude attenuation, they chose nitrocellulose and the boron-barium chromate mixture. They evaluated polyethylene, polysulfides, silicones and epoxies as a combination binder-carbon source-dispersant. Since the efficiency of thermite as a radiating source is less than 10 percent of the magnesium-Teflon®-Kel-F® wax composition, they concluded thermite did not justify further investigation. Performance of the experimental compositions was compared to the USAF TAU-15/B decoy flare whose standard composition is 54% magnesium gran 15, 30% Teflon® #1 and 16% Kel-F® #40 wax. The US Flare Division team did not report any significant technological advancement except for a minor energy per gram improvement with addition of 5% anthracene. In this work, the anthracene was added to increase the amount of hot carbon particles as a combustion product known to radiate as a high emissivity greybody radiator.

In an effort to reduce the radiative signature of missiles, about 1960 Mr. Breslow and Mr. Richard A. Breitengross of NOTS added an unspecified alkali metal salt to the Sidewinder 1-C propellant grain to suppress the booster radiation. They reported a dramatic reduction in the plume radiation.

Mr. David A. Merrell of the Hughes Aircraft Company Infrared Laboratories conducted an extensive study of the feasibility of a modulated pyrotechnic flare about 1960. These experiments lead to development of an electric modulated flare using an incandescent filament instead of a pyrotechnic source. The latter produced an output of about 14 W/sr in the 2μm to 2.5μm bandpass region with an electric input of 475 W.

About 1960, the Geophysics Research Directorate of the Air Force Cambridge Research Center and the Weapons Guidance Laboratory of WPAFB supported work at Block Associates Inc., Cambridge Massachusetts for infrared filtering of the magnesium flare. Mr. Myron J. Block and Mr. Merle J. Persky proposed to change the spectrum of an MTV flare to match that of an aircraft by surrounding the flame with a three-inch diameter filter envelope to remove undesirable wavelengths. To protect the filter envelope, they introduced a coaxial stream of air at 150 miles per hour between the flame and the envelope. In laboratory experiments, they showed the envelope could be protected. They used a Pyrex® tube around the RITA flare and also explored a Corning 7-56 filter.

In 1960, Dr. Hal Waite and Mr. M. Bressler of Aerojet-General reported developments in infrared chemical sources. They reported that carbon particles are a unique source of the observed radiation. To improve the output, they added anthracene to get more carbon products and noted that at altitude, compositions containing anthracene exhibited better performance during the burn when the nozzle was restricted as compared to unrestricted burns.

In a late 1960 report for the Targets Development Laboratory of Eglin Air Force Base, Mr. L. K. Lantz, Mr. R. Hopkins and Dr. Waite of Aerojet-General conducted tasks to fabricate infrared decoy flares for ground and air tests. The prime requirements were good altitude performance and large amounts of radiation in the 3.0μm to 4.5μm bandpass region. They claim the sensitivity of the magnesium-Teflon® reaction to changes in pressure has been reduced by the use of an Aerojet-General developed, blending process that provides utmost homogeneity with the result that there is no change in the burning time from sea level to 40,000 feet and only minor changes to 60,000 feet. Earlier work by Aerojet-General showed that 5 percent incorporation of anthracene enhances the radiation of the basic composition without degradation of its altitude performance. When using this additive, the Aerojet-General team reported energy increases of 8 percent in the 1.8μm to 2.8μm bandpass region and 25 percent in the 3.0μm to 5.0μm bandpass region. The static and airborne test flares, type unspecified, are 1.75-inches in diameter by 11.40 inches long and contain a pressed grain formulated to burn 90 seconds during static test. The flare compositions used in these evaluations are: (1) main flare composition: 33% Teflon®, 62% magnesium (22μm particle size), and 5% powdered anthracene, (2) booster composition: 28.5% Teflon®, 52.25% magnesium (22μm particle size), 14.25% ignition booster mix, and 5% powdered anthracene and (3) ignition booster mix: 46.3% zirconium (2.3μm particle size), 29.7% molybdenum trioxide, 19.0% chromic oxide, and 5% nitrocellulose.

In 1961, Mr. Sarnow of the Air Research and Development Command at WPAFB awarded a contract to the Midwest Research Institute of Kansas City, Missouri for a new type of flare that would produce a large cloud of finely divided radiating carbon particles formed by the decomposition of an acetylenic fuel. The prototype decoy used isopropenylacetylene (IPA) to generate the radiating cloud. The goal was to achieve a high signature in the 3μm to 5μm bandpass region. The radiating carbon

produced a greybody signature with insufficient energy to serve as a decoy. The concept for the decoy design is an aerodynamic shape with fins on the rear that looks like a pod. The size is 5.5 inches in diameter by 50 inches long. This shape is compatible with the AN/ALE-14 ejector system. The IPA is pumped into the interior combustion chamber where it is ignited with a hypergolic material to produce hot carbon and some thrust. When dropped from the B-52 bomber, the hot carbon cloud being released from the assembly becomes a decoy for the aircraft. Heaters were added because cold temperatures at high altitudes are a problem for efficient combustion. They considered external injection of chlorine trifluoride to increase the radiative output. If the latter failed, a bipropellant would be tried. Three prototypes were made and sent to NAD Crane for safety tests. There were problems with the acid pumps and corrosion. Eventually, the concept was abandoned because the spectral intensity was too low to serve as a decoy.

About 1966, Mr. John C. Trowbridge and Mr. William Lai of the United Technology Center, Sunnyvale, California (UTC) received a contract from the Research and Technology Division of Eglin Air Force Base to develop controllable infrared flares. They wanted to generate infrared signatures with a hybrid combustor. This is a burner-like device that supplies a gaseous oxidizer (oxygen) to a solid fuel surface. In this case the fuel grains are 2.5 inches in diameter by 12 inches long with a 1-inch hole through the entire grain. The fuels are either a castable rubber base or a methymethacrylate polymer base. Varying the oxidizer and the basic fuel controls the output. Shrouding the flare improves altitude performance. Some purported advantages are start and stop capability, controllable infrared radiancy, handling and storage safety, and manufacturing simplicity.

In a related experiment, United Technology provided hybrid flares for test. These consisted of a cylindrical hollow flare grain wherein flowing gaseous oxygen is ignited by burning propane. The units are 24 inches long by 3.5 inches in diameter. The grain consists of polybutadiene, polybutadiene-acrylonitrile, and polymethylmethacrylate with various amounts of aluminum as a fuel. The combustion could be started and stopped. The units were tested in a no-wind and wind environment, the latter being 50 to 60 knots. They wanted to use these units on drones carrying Radio Frequency (RF) systems and to determine compatibility between RF and infrared systems.

In 1967, Dr. Edwards of Air Development Test Center at Eglin Air Force Base, requested Picatinny Arsenal to improve the ALA-17 flare. The Air Force wanted a quick fix to the poor rise time of the ALA-17 flare. They also required that a single ALA-17 flare would have decoy capability to protect B-52 bombers in Southeast Asia against seekers operating in the 2μm to 3μm and 3μm to 5μm bandpass. This resulted in the development of the ALA-34 flare, which has a grain twice the length of the ALA-17 flare.

While the Mk 46 Mod 0 flare was in production during 1969 at NAD Crane, China Lake and Crane teams were asked to replace the RAPEC ignition mix with a safer

mix and to take a closer look at the pull wire igniter from a safety point of view. Mr. Allen of China Lake proposed a sodium azide-Teflon® igniter mix as a substitute for the RAPEC mix. Engineers at Crane did not support this mixture because of its azide content. Another proposed mix, supposedly less friction and electrostatic sensitive than RAPEC, was 57% sodium azide, 12% Teflon® #7, 31% boron, and 4% polymethylvinyltetrazole binder. China Lake also proposed another igniter mix, which was a vapor-deposited vacuum coated aluminum-tungsten trioxide material. The effort continued during 1970. Potassium azide and lithium azide were also considered by China Lake as a replacement for the sodium azide. Cab-O-Sil, which is fumed silica, was added to improve its effectiveness.

During 1969, NOTS explored three different igniters for the Mk 46 Mod 0 flare these being a plug release igniter, a shoulder-stop igniter and a pneumatic igniter. Dr. Raison and Mr. James Ross of the Illinois Institute of Technology Research Institute completed their contract for the miniaturization of the pneumatic igniter in mid-1969. In 1970, China Lake reported that the shoulder-stop ignition device is best of the four ignition ideas based on a value engineering study. The shoulder-stop ignition device was incorporated into future decoy designs.

In 1969, China Lake pointed out the need for compositions that were more effective in the 3µm to 5µm bandpass region. They suggested that the compositions be tailored to aircraft such as helicopters and that the compositions be more effective against multi-bandpass seekers. Emphasis is placed on the need for more power in the 3µm to 5µm bandpass region.

The China Lake team began thinking about a miniature flare for helicopters in the mid 1969 time frame. They proposed to develop a 1-inch diameter by 4-inch long flare. Later, the Mini-Flare was reported to be 2.75 inches long.

Three different grain designs were proposed for study by China Lake in 1969. These are an internal 8-point star, an internal-external burning grain, and grain that is burning only on the exterior surface. The grain designs needed to fit into the Mk 46 Mods flare configuration, that being 1.43 inches in diameter by 5.81 inches long. This configuration is compatible with AN/ALE 29 and AN/ALE 39 flare chaff dispensers.

Mr. James W. Richardson of NAD Crane explored qualification of ground and balled (atomized) magnesium for infrared decoy flare production as described in a 1971 report. The objective of this effort is to prove that either ground magnesium or atomized magnesium is suitable for use to manufacture infrared decoy flares. After all the qualification teats were conducted, which provided positive results, the production drawings were amended to allow the contractor the option to choose either type of magnesium to produce the flares required by the contact. The qualification effort involved the Mk 42 Mod 0 flare, the Mk 43 Mod 0 flare, the Mk 46 Mods, and the Mk 48 Mod 0 flare.

With respect to manufacturing improvement of the cartridge case, China Lake evaluated a redesigned 2-piece flare case joined by a magnaform process, which uses a high magnetic field to make the joint. Development of improved grain configurations and infrared composition was also continuing at China Lake during 1971. Performances of composition PL 7078 and composition PL 6720G with added graphite were compared. Both compositions extrude well. China Lake made grains with a 12-point internal star configuration and with a 12-longitudinal holes configuration. They reported that composition PL 6920G burns more quickly than composition PL 7078. The radiant intensity in both the 2μm to 3μm and 3μm to 5μm bandpass region was greater for composition PL 6920G. The 12-point internal star grain configuration burned more rapidly that the 12-hole grain configuration for both composition PL 6920G and composition PL 7078. This performance trend is similar for changes in altitude, wind velocity and ignition orientation. Composition PL 6920G with the 12-hole design had a very short rise to peak radiant intensity. The same design and composition was evaluated for radiant intensity at 40,000 feet altitude with 600 feet per second simulated airflow in the 2μm to 3μm and 3μm to 5μm bandpass region. The 2μm to 3μm bandpass region was greater in infrared radiant intensity than that in the 3μm to 5μm bandpass region.

Mr. Raymond Szypulski in NAVAIR as reported in a 1971 report assigned China Lake the task to develop second generation infrared flares with more infrared output in the 3μm to 5μm bandpass region and less in the 2μm to 3μm bandpass region. Dr. Handler, Mr. Harp, Mr. Sbrocca and R. Stassart of China Lake undertook this task. Their thrust was to develop formulations that have the desired spectral output by exploring metal/metalloid reactions with fluorine and oxygen containing oxidizers and to find binders that are not likely to form graphitic forms of carbon in the plume in order to maintain spectral purity rather than greybody radiance. To improve flare efficiency, their goal was to gain understanding of the physical processes, which occur on or at the burning surface. To further the idea to eliminate graphitic carbon originating from the Vitel® or Viton® A polymers, they considered many binary systems, which avoid these binders. They tried mixtures of aluminum, boron, calcium, calcium disilicide and magnesium with complex fluoride oxidizers. The best were potassium hexafluorophosphate and either calcium disilicide or aluminum as the fuel. They noted the spectral inversion was also observed in a complex system containing magnesium, potassium hexafluorophosphate, ammonium perchlorate and either Vitel® or Viton® A as the binder. They also considered high-oxygen-containing binders that do not have a sustained carbon-to-carbon backbone to obtain binder systems that would not produce graphite upon pyrolysis. Prototypes of these materials are the commercially available acetals and formal polymers Celcon® and Delrin®.

Continuing in 1972 toward their thrust to achieve a better color ratio (aka spectral inversion) between the 3μm to 5μm and 2μm to 3μm bandpass region. Mr. H. W. Kruse and Mr. Sbrocca of NWC, China Lake evaluated both pressed and cast compositions by introducing additives to the basic magnesium-Teflon® formula. They reported the mixture of Vitel®, potassium hexafluorophosphate, and

ammonium perchlorate as being encouraging in the 3μm to 5μm bandpass region. The magnesium, ammonium perchlorate, potassium hexafluorophosphate and Vitel® PE 222 formula gave a good color balance but was too low in radiative intensity. The best formula for an improved color ratio using Sylgard® to make a cast grain was 46% magnesium, 28.9% ammonium perchlorate, 1.4% Viton® A and 23.5% Sylgard® 182, called formula 256. Since the time to peak intensity was excessive for the Sylgard® formula, they introduced an 8-point star grain and a center bore hole configuration to get a larger burning surface. Later work by Dr. Melvin P. Nadler and Mr. Sbrocca of NWC, China Lake reported the Sylgard® formula as being not worth continuing. It performed well at ground level but not at a simulated altitude of 25,000 feet. Sodium azide was considered to increase the burning rate and increase the radiant intensity without loss or band ratio reversal. They proposed a new binder system R-45M hydroxyl terminated polybutadiene and possibly a castable fluorocarbon. Other fuel and oxidizer combinations were proposed in an attempt to produce chemical species, which emit in the 3μm to 5μm bandpass region. A pressed boron-Viton® A-ammonium perchlorate composition was tried in an attempt to produce boron oxyfluoride, the monomer of trifluoroboroxine. The monomer is stable at high temperatures and has band emissions in the 3μm to 5μm bandpass region. Small pellets of (1) boron-Teflon®-ammonium perchlorate, (2) boron-potassium hexafluorophosphate-ammonium perchlorate, and (3) boron-ammonium perchlorate-Viton® A were tested to see if they would burn. All burned at ground level, but only boron-ammonium perchlorate-Viton® A system looked promising. Pressed grains were also made with potassium hexafluorophosphate, fluoropolysiloxane (FS 1265 fluid), and Celcon® an acetyl copolymer based on trioxane supplied by the Celanese Corporation of America.

Mr. Foote and Mr. Michael Mamula of China Lake also were working to increase the color ratio. Using the EX 49 Mod 0 flare as their base design, they evaluated hardware changes for better ignition, studied different grain configurations such as the 12-point star and 12-hole variants to achieve greater surface areas, and additions of different amounts of graphite. After improving the ignition, test firings in mid-1972 indicated that the 12-hole configuration gave a combustion profile closer to the desired regressive burning. Ignition problems continued with the EX 49 Mod 0 flare, which by early 1973 was designated the Mk 49 Mod 0 decoy flare. Changes were made to the crimp at the mouth of the flare case. Further ground testing at NAD Crane and air testing at the Point Mugu test center showed that the ignition problems had not been resolved. This put further development of the Mk 49 Mod 0 flare into jeopardy. Some of the ignition problems were attributed to the CT-144 ignition mix.

Mr. Kruse and Mr. Breitengross of NWC as reported in 1971 were assigned the task to improve the efficiency of the infrared flare combustion reaction. They observed that some energetic ingredients do not react efficiently because of physical separation between the fuel and oxidizer. To overcome this deficiency, they attempted to coat the fuel with an oxidizer. They were aware of the work at the Illinois Institute of Technology Research Institute, which does the inverse; that is to

coat aluminum onto oxidizers such as tungsten trioxide, vanadium pentoxide, and potassium perchlorate by decomposition of an aluminum alkyl. The NWC China Lake team tried coating of boron with barium chromate and boron with potassium nitrate using non-aqueous solvents.

Work continued at NWC China Lake during 1972 to improve flare performance efficiency of magnesium-Teflon®-Viton® A (MTV) compositions and those containing Vitel® as well.

An urgent message dated 5 May 1972 directed the development of a flare to protect helicopters and low slow fixed wing. The problem was that although the AN/ALE-29A chaff dispenser existed which could dispense the Mk 46 Mod 0 decoy flare or the Mk 47 Mod 0 decoy flare, the dispenser had not been fitted to helicopters. In the interim, the helicopter operators wanted protection now. In response to this deficiency, the NWC team used N-35 propellant also called composition PL 9001 for the infrared radiating medium to make the Mk 50 Mod 0 decoy flare. The Mk 50 Mod 0 flare is launched from the AN-M8 pyrotechnic pistol. Units were immediately tested against the Redeye seeker, a surrogate for the SA-7 ground-to-air infrared missile threat. Two thousand decoys were shipped to the fleet in June 1972, a remarkable feat. Decoys were also shipped to Air Force units in Southeast Asia. NOS Indian Head followed with production of 50,000 units. Since there were no dispensers on helicopters, protection was achieved by a hopefully tethered crewman stationed in the doorway of the helicopter manually firing a Mk 50 Mod 0 flare from the hand-held AN-M8 pistol at the smoke trail of incoming missiles. This was the interim solution until dispensers could be installed, which then could dispense the existing Mk 46 Mod 0 decoy flare or Mk 47 Mod 0 decoy flare. Production of the Mk 50 Mod 0 decoy flare continued during 1973.

In 1973, NWC China Lake proposed to design and fabricate a large flare about 2.75 inches in diameter by 8 inches long. They planned flight tests to demonstrate feasibility that this large decoy flare was capable of providing protection to an aircraft such as a fighter while operating with the afterburners engaged.

Dr. Clyde F. Parrish, Mr. James E. Short, Jr., and Mr. William T. Biggs of NAD Crane reported an alternate method for production of Mk 48 Mod 0 flares in 1973. Their method is based on the radiation polymerization of a binder/oxidizer system. Chlorotrifluoroethylene, the monomer used, is completely polymerized by radiation doses less than 5 megarads. Because of the density involved, no special adjustment for concentration of either the oxidizer or fuel is needed. The voids in the magnesium are simply filled with the gaseous monomer.

As a part of a high Mach flare study by Mr. S. W. Lim in 1973 and configuration studies by Mr. J. O. Vindum in 1973 and Mr. John T. Lamberty in 1971, a 1973 report describes development of a shielded flare in the ALA-17 flare configuration for the AN/ALA-20 ejector set. They compare the radiant intensity in the 3μm to 5μm bandpass region of a freestanding grain to a perforated can flare. The

perforated can is four times better in maximum infrared output and has a better rise to peak intensity. In an early design, a conical nose shield is placed on the nose of the device to shield the combustion products from degradation due to the windstream. They also investigated the perforated can concept theoretically. Analysis showed the mass flow rate and ignition rise were improved significantly over the freestanding grain. They surveyed possible new fuel and oxidizer materials including conventional, pyrophoric and hypergolic for use in infrared flares. They considered several concepts for a flare such as a (1) rocket propelled with fins and a perforated can on the nose end, (2) rocket propelled, Telejet, Teleskirt, with a perforated can on the nose end, (3) perforated can flare with a shock wave cone on the nose, (4) time delay flare, (5) tethered flare, and (6) a perforated can flare in a cylindrical shape. These concepts were tested in a chamber at 2.0 Mach and at 50,000, 40,000, and 20,000 feet simulated altitude. The perforated can was made of steel, with 48 ports each 0.25 inches in diameter. A 2.682-inch diameter by 4 inches long pellet consisting of 58.3% magnesium, 38.8 Fluon®, and 2.9% Laminac® is assembled into the can. During the effort, the investigators developed a method for predicting the plume size of a flare burning in a supersonic windstream. They also created a mathematical model for the ignition of a flare in windstream and developed a flare trajectory computer program.

Dr. Donald. J. Eckstrom, Mr. P. H. P. Chang, and Mr. Robert T. Rewick of Stanford Research Institute (SRI) Menlo Park California reported studies of advanced flares in 1982. They wanted to achieve a better color ratio between the 3µm to 5µm bandpass region and the 2µm to 3µm bandpass region by introducing additives to the basic magnesium-Teflon®-Viton® A composition. The preferred ratio is for the long wavelength to be significantly larger than the short wavelength. After exploring candidate molecular emitters in the 3µm to 5µm bandpass region, they stated the best composition was 32% magnesium, 14% Teflon®, 14% Viton® A, 37% potassium perchlorate and 3% carbon. The mixture gave a 2.5 fold increase in the color ratio and only a 25% reduction of energy in the 3µm to 5µm bandpass region. They stated the best emitter was carbon dioxide. They added isotopic carbon 13 to counter atmospheric attenuation.

Pyrophoric Flares, Liquid or Solid Materials

Prior to 1968, Dr. N. W. Rosenberg and Mr. W. K. Vickery of the Air Force Cambridge Research Laboratory (AFCRL) Laurence G. Hanscom Field, Bedford Massachusetts and Dr. D. B. Ebeoglu of Eglin Air Force Base reported measurement of infrared emissions from liquid pyrophoric fluids consisting of a mixture of 80% trimethylethylene (TME) and 20% triethylaluminum (TEA). They observed that the material was not affected by altitude when dispensed at 10, 000 feet and that the power was reduced by a factor of 10 at speeds of 275 knots in comparison to static performance.

In 1968, Mr. Leonard Spialter of the Chemistry Research Laboratory, Aerospace Research Laboratories at the Office of Aerospace Research of WPAFB considered

the potential of pyrophoric materials for use as infrared decoys. He excluded hypergolic materials in the study but included metallic powders, organic powders, inorganic and organometallics. He made a simple model as follow-on to the MS thesis of Major Norman Quigley in September 1967 - March 1968 at the Air Force Institute of Technology (AFIT). In his model, Mr. Spialter took into account the size of the fireball, loss of forward velocity, centroid seeking, paired clouds, etc. In the model, the target is traveling at Mach 0.9, the missile is traveling at Mach 2.0 and the altitude of the encounter is 50,000 feet. Dispensing 20 grams per second and at a standoff distance of 0.5 miles, radiance values are 4 kW/sr. He predicted the vulnerability envelope for the pyrophoric fireball to be about 44% of a conventional flare, that the fireball effectiveness is not greatly improved by increasing the diameter, and that dual ejections had an advantage and gave increased protection when ejected at proper time intervals. He conducted ground emission experiments at Eglin Air Force Base in March 1968.

Under contract to Mr. Vickery of the Aeronomy Laboratory at AFCRL, Dr. Katz, Mr. Ase and Dr. Raison formed a team at the Illinois Institute of Technology Research Institute to study liquid pyrophorics for countermeasures. The team made small-scale laboratory studies on the rheological and combustion properties of aluminum alkyls with a number of additives. Larger scale work was extended to flight tests in which 2-pound and 4-pound charges of pyrophoric materials were dispensed from an F-100D aircraft at 10,000 feet altitude while infrared measurements were made with an F-4C aircraft trailing 10,000 feet behind. All the pyrophoric materials exhibited very rapid rise times of less than 0.250 seconds and very high intensities in the long wavelength 3.9µm to 4.9µm region. Intensity was much lower in the region of 1.7µm to 2.7µm. They compared their results to the RR-80 flare. They stated that the ratio in the two wavelength regions could be useful for countermeasure against two color seekers. Mixtures tested included TEA and TMA in a range of mixtures with octane, pentane and polyisobutylene.

At the request of the NOL White Oak, about 1971, Mr. Ronald L. Blecher and Mr. Reagan Layne Dubose Jr. of Hycor, Inc., North Woburn Industrial Park in Woburn Massachusetts explored explosive dissemination of a gelled pyrophoric fuel intended for a ship decoy defense system. Triethylaluminum was the principal pyrophoric fuel in the study. In 1974, based on experiments during an Internal Research and Development Program (IRAD), Dr. A. Hirschman of NOL White Oak stated that the gelled pyrophoric of triethylaluminum did not work. This prompted the Hycor team to change to a ceramic felt wick saturated with a mixture of 75% TMA and 25% TEA. The wick is about 1 square inch and holds about 2 grams of material. They recorded the radiant intensity of a single wick in the 8µm to 14µm bandpass region and in the 3µm to 5µm bandpass region. They planned to load 1000 wicks into a Rapid Blooming Offboard Chaff (RBOC) cartridge. Their goal was to achieve a fall rate of less than 5 feet/second and an apparent temperature in the 8µm to 14µm bandpass region of at least 50 °C when viewed against a zero degree Celsius background. After initial laboratory investigations, they planned to test the RBOC round against captive threat surface-to-surface missile seekers.

Dr. D. B. Ebeoglu and Mr. C. W. Martin of the Armament Laboratory at Eglin Air Force Base and Dr. N. W. Rosenberg and Mr. W. K. Vickery of AFCRL at Hanscom Field undertook infrared signature measurements under static and dynamic environments. The experiments were conducted in chambers at Eglin Air Force Base and NWC China Lake and the results were reported during a 1974 meeting. Using kerosene as a reference they tested six pyrophoric materials in the laboratory and measured the radiant intensity in the 2μm to 5μm bandpass region at 60,000 feet simulated altitude with wind speeds of 300 feet/second. The six materials were: TEA, tri-n-propylaluminum (TNPA), diisobutylaluminum hydride (DIBAH), diethylaluminum chloride (DEAC), a mixture of 80% TMA with 20% TEA by weight, and a mixture of 60% diethylaluminum hydride (DEAH) with 40% TEA by weight. The flight test at 10,000 feet altitude gave ambiguous data. They concluded that pyrophoric materials offer a high radiation figure of merit in the 4μm to 5μm bandpass region and also in the 2.5μm to 3.3μm bandpass region with no airflow. They reported that the infrared signature from pyrophorics is not affected from sea level to 60,000 feet altitude. They could not model the effects of wind adequately. Their overall conclusion is that pyrophorics were promising as infrared decoys.

In 1973, Mr. Vickery of AFCRL at Hanscom Field requested NWC China Lake to measure the radiometric and spectrometric characteristics of TEA, TNPA, DIBAH, DEAC, DEAH, and a mixture of 66.5% TEA and 33.5% DEAH. Investigators at the AVCO Systems Division Wilmington Massachusetts also participated. Infrared radiant intensity data were collected at 40,000, 30,000, 20,000, and 10,000 feet altitude in both still and moving airstreams.

Mr. L. J. Larson of Hycor Inc conducted an Advanced Cost Effective (ACE) flare program for the Avionics Laboratory at WPAFB. The 1981 report covers work started in 1978. The objective of the ACE project was to develop a pyrophoric flare design, which was compatible with the current ALA-17 pyrotechnic flare canister and the AN/ALE-20 dispenser system for the B-52 bomber aircraft. A key technology to be addressed was to develop a means of metering the liquid fuel to achieve adequate burning times and radiant intensities. Several flare designs were tested. One had a bladder in the inner case. Another used a piston to expel the pyrophoric fuels. Typically the fuel was a mixture of TMA, TEA, and DEAH. Diethylmagnesium (DEM) or DEAC is added to reduce the freezing point of the mixture. The spectrum of jet fuel was compared to the pyrophoric fuel mix. A tethered design was tested to reduce tumbling. Two sizes tested were 2.5 inches in diameter by 5 inches long and 2.5 inches in diameter by 10 inches long. The long design was prompted by the poor reliability of the ALA-17 flare and the AN/ALE-20 dispenser, which made it necessary to dispense two or more flares to protect the B-52 aircraft. The long flare would replace the need for dispensing two flares.

About 1982, Dr. William E. Howell, Dr. John A. Lafemina, and Mr. Gary Roan of NRL were developing decoys compatible with the AN/Mk 36 Launcher for surface ship protection. Pyrophoric foils, emissive chaff and catalyzed carbon cloth were

being evaluated. They obtained temperature-time profiles for each material type, and radiance, area, and spectral measurements. A team lead by Mr. J. Ganjei at the Naval Research Laboratory (NRL) studied catalyzed combustion of carbon fibers from carbon fiber-resin composites. Mr. Ganjei, Dr. H. D. Ladouceur and Mr. A. Saunders also of NRL studied how a liquid pyrophoric can ignite carbon cloth. Impregnating the cloth with 10% lead acetate lowers the spontaneous ignition temperature of the cloth. They also studied aluminum foil backed materials ignited by a triisobutylaluminum alkyl and noted that TEA and TMA can also be used. They proposed using carbon particulates for aircraft decoy flares.

Mr. James R. McDougal, Mr. Robert R. Gross, and Mr. Gary P. Anthony of Boeing in 1982 conducted an effectiveness analysis of pyrophoric and pyrotechnic flares in defense of strategic aircraft against two-color missiles. They constructed a digital model for that purpose, conducted the analysis and concluded that pyrophoric flares offer substantial improvements over pyrotechnic flares, that upward ejection is not optimum, and that a two second burning time is the absolute minimum.

Castable Compositions for Decoys and Flares

In the early 1960s, researchers were exploring manufacturing processes for making decoy flare grains. The shock-gel process (aka coacervation process) during that time period was used to prepare infrared composition, which then is extruded to make MTV grains. Mr. Kruse and Dr. Handler of NOTS explored a modified vacuum-casting process to make infrared flare grains. If successful, the vacuum-casting process was expected to improve the efficiency of grain manufacture over the coacervation process. Example binders that they investigated were fluoroacrylates, fluoromethacrylates, Viton® LM, and Viton® LM cross-linked with carboxy-terminated polybutadiene (CTPB). The composition made by the vacuum-casting process contained 18-25% by weight of the binder ingredient. They reported the infrared output of grains made by the vacuum casting process in the 2μm to 3μm bandpass region to be comparable to grains made by extruding MTV.

A U. S. Patent 2,984,558 for a Plastic Pyrotechnic Compound by Mr. Edward Rolle and Mr. John Q. Tabor, Jr. dated 16 May 1961 addresses a tracking flare with composition that can be cast or molded at room temperatures without the application of either heat or pressure, and which will harden without developing cracks or fissures. The patent discloses a formula that is equal amounts by weight of a resinous compound and a fuel. The resins are Laminac® Resin #4128 and Laminac® Resin #4134, both unsaturated polyester resins. The fuel is 1-part magnesium powder (70% through 325 mesh) and 2-parts potassium perchlorate or ammonium perchlorate as the oxidizer.

Development of compositions with polymeric melt system technology is disclosed in three patents. U. S. Patent 3,094,444 for Solid Composite Propellants Containing Lithium Perchlorate and Polyamide Polymers by Mr. Ross M. Hendrick and Mr. Edward H. Mottus dated 18 June 1963 discloses a mixture that is heated to 225 °C.

A homogeneous fluid viscous mass results at that temperature. U. S. Patent 3,067,074 for Slow Burning Propellant Composition by Mr. William A. Gey of NOTS dated 4 December 1962 describes a mixture of molten Teflon® with a solid oxidant. U. S. Patent 3,013,871 for a Gas-Generating Composition by Mr. Paul O. Marti, Jr. dated 19 December 1961 uses a softened plasticized styrene-acrylonitrile copolymer as a binder fuel.

About 1962, Mr. Cronk of Eglin Air Force Base sponsored a task to conduct research and determine feasibility of castable infrared flares. Dr. Waite, Mr. Paul M. Kirkegaard and Mr. Richard A. Whiting of Flare-Northern performed the work. The team noted that after seven years of work related to the magnesium-Teflon® flare composition, a problem still remains with compositions containing Kel-F® wax. Those compositions exhibit unsatisfactory ignition and unsatisfactory combustion at altitudes above 100,000 feet and show marked attenuation in radiative output and a decrease in burning rate with altitude and airflow. In addition, the combustion tends to snuff-out at velocities above Mach 3. The researchers claimed some improvement of properties is available through use of wet-blended and pressed grains of magnesium-Teflon® with radiation enhancement additives. However, they asserted that significant improvement in the state-of-the-art for infrared chemical sources must evolve from the use of a new source material. They claimed to have developed such a material in the form of a bulk polymerizable fluorocarbon that replaces the Teflon®. They made cast flares based on acrylic and methacrylic esters of fluoroalcohols. One example is copolymerization of fluoroheptylmethacrylate with fluorocarbons. They also made liquid/slurry flares based on fluorophthalate esters of the above alcohols. Their theoretical analysis of fuels other than magnesium showed no improvement over magnesium when substituting them for magnesium. The investigators also explored anthracene and phenanthrene as additives. They reported that chaff-loaded or staples-loaded cast flares increased the linear burning rate from 0.03 to greater than 0.2 inches per second and also were better at altitude. To further the technology, the team attempted to make ultraviolet radiating flare compositions based on aluminum and aluminum perchlorate and made cavity flares to enable tailored combustion properties.

In 1966, Dr. Hal Waite formed Ordnance Research Incorporated (ORI) Fort Walton Beach Florida. There he continued his fluorocarbon polymer and cast flare composition development primarily under contract with the Air Force at Eglin Air Force Base.

Mr. Sarnow of the Avionics Laboratory at WPAFB funded the Flare-Northern Division of the Atlantic Research Corporation to develop a solid cast source. The objective was to incorporate a solid cast infrared flare in a dispenser system compatible with the AN/ALE-20 dispenser installed in an Air Force bomber aircraft. In 1965, Mr. Reed of Flare-Northern reported that end burning cast units did not burn fast enough even with additives. His base mixture consisted of polyfluoroheptylmethacrylate (PFHM) and magnesium. Next he made star-

perforated grains to accelerate the burning rate. He also introduced tetrachloroanthraquinone, violanthrone, pyranthrone, tetrakis-(anthraquininoneyl amino)-anthraquinone and isoviolanthrone as additives. He added 0.032 diameter copper wire (similar to staples or chaff in this application), which he placed axially into the center of the grain. With this he achieved a four-fold burning rate increase. He also tried three silver wires placed axially 120 degrees apart. This technique also increased the burning rate. He concluded that the flare with the internal burning star, with isoviolanthrone as an intensity additive, and aluminum chaff as a burning rate accelerator was the best combination.

In 1965, NOTS investigators continued to explore the propellant casting process to make infrared flares. The binders were fluoroacrylates and fluoromethacrylates. Viton® LM, being less expensive than acrylates, was used as a plasticizer. Magnesium was the fuel and Teflon® was the oxidizer. A modified vacuum casting process was used to load the flares. As part of this work, Dr. Handler of NOTS China Lake explored the solubility of magnesium perchlorate in various polymers. The maximum solubility of magnesium perchlorate into a mixture of 2 parts butylacrylate with 1 part acryloacrylate is 50%. He also explored the solubility of magnesium perchlorate in vinyl monomers and other binders like fluoroacrylates-methacrylate in a Viton® LM polyamine system. Dr. Handler also evaluated binders containing oxidizers for cast flares.

Missile and Rocket Igniter Developments

In early 1944, Dr. Hart at Picatinny Arsenal studied coating agents for magnesium and magnesium-aluminum alloys. During that period, it was customary to use linseed oil to protect magnesium from moisture and to act as a binder in tracer and other pyrotechnic compositions. In this instance, metal powder is coated by immersion in a 5 percent aqueous solution of sodium dichromate and sodium hydrogen sulfate at room temperature. The coated magnesium was tested in igniter compositions in 37mm tracer ammunition. During the study, Dr. Hart observed that (1) finer magnesium is more reactive with moisture than is coarser magnesium, (2) 50/50 magnesium/aluminum alloy is less reactive with water than either magnesium or aluminum alone, (3) the presence of strontium nitrate improved the resistance of magnesium to the reaction with water and (4) sodium oxalate accelerates the reaction of magnesium with water. He stated that no earlier work to coat powdered metals was found.

As the work progressed, in 1944 Dr. Hart developed an improved igniter “K” composition containing dichromated 50/50 or 65/35 magnesium/aluminum alloy instead of magnesium. Extended storage tests of the improved igniter composition demonstrated it to be more stable at elevated temperatures and high relative humidity and also less sensitive to friction than the standard igniter “K” composition. With good test results during firing tests at Aberdeen Proving Ground Maryland in 1945, they recommended putting the improved igniter composition into 37mm and

40mm tracer ammunition and to study using the dichromated fuels in larger caliber ammunition.

In 1948, NOTS began design of the folding-fin aircraft rocket (FFAR). The initial H-9 propellant was replaced with N-4 propellant in the fall of 1950. The use of the N-4 propellant introduced a low temperature ignition problem into the Mk 125 Mod 0 igniter then in use. Mr. N. C. Eckert of NOTS conducted an investigation of low temperature ignition. He modified the charge in the igniter to consist of 8 grams of black powder and 2 grams of vinyl-coated magnesium powder. This modified igniter is designated the NOTS Model D634 Igniter.

The NOTS Model D634 igniter gave satisfactory ignition in the NOTS Model 103G 2.75 inch rocket motor above minus 40°F with failures below that. The NOTS Model 103G motor is the prototype of the 2.75 inch Mk 1 Mod 1 rocket motor. By May 1951, a redesigned igniter was developed. It was designated the NOTS Model D639 igniter later to be designated the Mk 125 Mod 2 igniter. Mr. Eckert of NOTS is credited with the development of the Mk 125 Mod 2 igniter. The NOTS Model D634 igniter and the Mk 125 Mod 2 igniter have the same charge, namely 8 grams of black powder and 2 grams of vinyl-coated magnesium powder. The Mk 125 Mod 2 igniter was incorporated into the 2.75-inch NOTS Model 103H rocket motor, which is the prototype of the 2.75-inch Mk 1 Mod 2 rocket motor. Later, it was observed that the Mk 125 Mod 2 igniter had a problem with the reaction of moisture with the magnesium powder. That subject is discussed in the section on Hydrogen Formation from the Magnesium-Moisture Reaction.

Federal Ordnance Incorporated (FOI), Mechanicsville Maryland produced the 2.75-inch FFAR rocket motor Mk 1 Mod 3 containing a Mk 125 Mod 2 igniter manufactured by Federal Ordnance Incorporated. The US Flare Corporation (USFC), Pacoima California also manufactured a Mk 125 Mod 2 igniter. At minus 65 °C, there were induced incipient hangfires in the Mk 1 Mod 3 motors with the igniters made by Federal Ordnance Incorporated but not with igniters made by the US Flare Corporation. This investigation assigned by the Navy BuOrd to NOTS lasted from October 1954 through February 1955. The lack of proper quantity of magnesium in the charge and non-homogeneity of the mixture are the assigned causes for the Federal Ordnance Incorporated igniter failures.

Atmospheric Pressure and Altitude Effects

It had been observed that when flare compositions are required to function at elevated altitudes and reduced pressure, performance drops off. Often the burning rate decreases and the radiant intensity is reduced. These undesirable effects are a major concern and many efforts were initiated to correct or at least minimize those flare performance deficiencies. After all, fighters and bombers will use the infrared decoy flares for self-protection at very high speeds and very high altitudes.

About 1959, Mr. Knapp of Picatinny Arsenal was under contract to the Air Force to develop an infrared flare that radiated in the 1.8μm to 2.8μm bandpass region. A composition identified as SI-119 was reported to be unaffected by increasing altitude up to 60,000 feet and above which it tapers off slightly. The constituents are molybdenum trioxide, chromic oxide, and zirconium. The peak energy output in watts and the efficiency in joules/gram or joules/cubic centimeter increased with altitude although the burning rate was constant with altitude. Mr. Knapp reports that in the first 12 seconds of combustion, the SI-119 composition is superior to Teflon® compositions. Compositions consisting of manganese dioxide-zirconium and molybdenum trioxide-barium nitrate-zirconium are reported to have very good ignition and burning characteristics at both high and low altitudes.

As part of an MS thesis from US Naval Postgraduate School, Monterey California, in 1962, a student studied the pressure dependence of the solid-state reaction between magnesium and Teflon®. He observed that at about 350 mm Hg ambient atmospheric pressure, the percentage of completion of the reaction dropped off exponentially to 12 mm Hg, the lowest pressure considered. He reported decomposition of Teflon® at about 425 °C and melting of magnesium at 650 °C. Steady state burning was observed at about 650 °C, the melting point of magnesium.

During the early and mid 1960s, NOTS engineers continued to study flare performance at high altitudes. They needed a method to obtain infrared output performance data of flares under actual use conditions. They installed a modified fuel tank under the fuselage of an A-4E aircraft and attached the flares to radial arms extending from the front of the tank and attached a radiation detector to a rear fin 14 feet from the flares. Associated electronics were mounted inside the tank. Feasibility flights at 30,000 feet altitude and 0.8 Mach indicated that the radiometer response was insufficient. They studied the discrepancy in the HARP facility. They also brought additional instrumentation to the task to determine the cause of the performance fall-off with altitude.

Functioning at very high altitude is a requirement of the magnesium-Teflon® composition. To further understand its behavior, in 1961, Mr. Besser of NOTS conducted studies for use of this composition for rocket grain igniters at 70,000 and 100,000 feet simulated altitude.

About 1961, Mr. F. Harshbarger and Mr. R. Herman of the General Dynamics Corp (GD), San Diego, California tested six flare formulations in their altitude chamber. US Flare Division of the Atlantic Research Corporation prepared the six test units. The test units are an end burning grain, 2.5 cm in diameter by 20.3 cm long. The grain weighs 150 grams and is made up of the NOTS Standard formula consisting of 54% magnesium gran -16, 30% Teflon® #1 600μm particle size, and 16% Kel-F® #10 wax. To that grain formulation two test units had lithium perchlorate and anthracene added, one test unit had tetranitrocarbazole and Epon 864 an epoxy resin added, and two test units had nitrocellulose and silicon dioxide added. These

test units were tested in the General Dynamics altitude chamber, which is 6-feet in diameter by 40 feet long and is capable of 92,000 foot simulated altitude. The thrust of the work is to determine the effect of altitude on the spectral output of the flares. A Perkin Elmer Model 108 rapid-scan spectrometer was used to obtain the spectra in the 1μm to 2.5μm and 2.5μm to 5μm bandpass region. The temperature was measured with a Leeds and Northrup optical pyrometer. At altitudes above 40,000 feet, the General Dynamics team reported the spectral radiance decreased as the altitude increased and the brightness temperature decreased with increasing altitude. The burning time generally increased with increasing altitude.

Inhibiting Technology for Flares

It is necessary to prevent the combustion reaction from flashing down the side of a flare grain ahead of the desired flame front in order to obtain smooth and efficient burning. Modifying or protecting the surface of the flare to prevent such undesirable ignition is known as inhibiting. During the early 1960s, Dr. Handler explored the use of 16 different inhibitors. He applied these to 1-inch diameter grains made with composition PL 6328, namely 54% magnesium gran -16, 30% Teflon® #1, and 16% Viton® A. Three different epoxy-coating agents seemed successful at ambient and cold temperatures. NOTS China Lake researchers also treated the surface of the extruded grain with hydrochloric acid before coating the grain with the inhibitor to improve adhesion.

As the work continued, the China Lake team learned that four commercially available resins prevented flash down on extruded grains made with composition PL 6328. Grains (0.913 inches in diameter) also were co-extruded with an inhibitor layer approximately 0.1 inch thick of 16% Viton® A, 35% titanium dioxide, and 35% carbon black. These methods did not materially affect the efficiency of the flares.

Work continued at NOTS China Lake into the early and mid 1960s to inhibit burning on the exterior of extruded and pressed infrared grains consisting of the magnesium-Teflon®-Viton® A formula. Grains with these formulations are difficult to inhibit. The non-sticking properties of Teflon® in the composition make adherence of the inhibitor difficult. Inhibiting the grain is a way to control the burning rate better. The NOTS investigators tried epoxy and proprietary coatings as well as wrapping with ethyl cellulose and/or glass tape. The burning times were longer with the tapes than for the resins with some exhibiting burn-through.

Burning Rate Modification

Dr. McEwan, Mr. Alvin S. Gordon, and Mr. Joseph Cohen, all of NOTS China Lake, developed a method in 1953 for increasing the burning rate of propellants by introducing metal wires such as copper, silver, aluminum, molybdenum, tantalum, and lead into the composition. The wire had to be a good conductor and have a high melting point. It was intended that these short lengths of highly conductive wires would conduct the heat generated at the combustion site into the composition

more rapidly to further promote the propagation of the flame front and thereby accelerate the burning rate. They made a submission for patent that was awarded as a Notice of Allowability on 5 August 1959. This concept was applied later to infrared decoy pressed and extruded compositions without success. With respect to decoy compositions, the addition of a few percent of conductive wire, then called staples or chaff, has an insignificant effect on increasing the burning rate. This is because decoy compositions already have a high content of conductive metal, for example 54% magnesium.

In 1975, Mr. K. L. Moore and Mr. Breslow of NWC conducted burning rate modification studies. Their approach was to thermally decompose diborane in a fluidized bed. They planned to make boron coated aluminum and magnesium by chemical vapor deposition of the decomposed diborane.

Gasless Delay Mixtures

In 1943, the U. S. Army standardized a nickel-potassium perchlorate delay developed by Mr. Owen G. Bennett and Mr. Jack Dubin for use in M204, M205, and M206 hand grenade fuzes. Their U. S. Patent 2,457,860 for Delay Fuse Compositions issued on 4 January 1949. This gasless delay mix consisted of powdered zirconium, powdered nickel, barium chromate, and potassium perchlorate. The barium chromate was used to regulate the burning rate. The Bennett delay was later replaced by a dichromated zirconium-nickel alloy delay developed by Dr. Hart of Picatinny Arsenal.

A new non-gaseous fuze powder for the M16-A1 delay elements for bombs containing barium chromate, manganese, and sulphur was developed about 1944 by Dr. Hart. It is better than the standard lead chromate-silicon delay.

An improved barium chromate delay powder for the 8 to 11 second delay was developed a year later by Dr. Hart, which contains 70.9 parts barium chromate, 27.1 parts manganese, 2 parts sulphur, and 2 to 3 parts ethyl cellulose. It is more stable, affected less by moisture, and more readily pelleted than the standard powder. An igniter, which can readily be pelleted, was developed containing 85 parts red lead, 15 parts silicon, and 2 to 3 parts ethyl cellulose.

During 1949, Dr. Hart started to develop a gasless, non-hygroscopic fuze powder. He conducted a detailed study of the burning characteristics of binary mixture containing barium chromate with zirconium and titanium. The use of zirconium powder involves considerable hazard. Hence, he went to a less hazardous zirconium-nickel alloy. The metals were protected with a dichromate.

Dr. Hart pointed out during his 1956 lecture that black powder customarily used to make delays, is an explosive and presents some hazards. To overcome the disadvantages of black powder as a delay powder, Dr. George C. Hale at Picatinny Arsenal, began work in 1929 on the development of non-gaseous delay powders,

making use of inorganic exothermic reactions similar to those used in thermite mixtures. The first non-gaseous delay powder was developed in 1931 for the M16-A1 primer detonator used in a bomb fuze. It contained red lead, silicon, and glycerine, the latter added as a binder. Even in small quantities, organic binding agents such as glycerine and linseed oil produce a significant amount of gas upon combustion.

During WW II and concurrent with the work going on at Picatinny Arsenal, a non-gaseous delay powder was developed by the Catalyst Research Corporation of Baltimore Maryland working under contract with the Navy and the Army Ordnance Corps. This composition contained catalytic nickel, zirconium, potassium perchlorate, and barium chromate. This mixture is based upon the exploitation of four simultaneous exothermic reactions having different burning rates. Although this delay powder was used successfully during WW II for hand grenades, there were difficulties similar to those encountered with the barium chromate, manganese, and sulfur delay powder. The burning rate was found to decrease with age. The nickel powder had to be produced under carefully controlled conditions by a special patented mercury amalgam process. The particle size of the zirconium required careful control for reproducible results. However, the powder appeared to be more stable in the presence of moisture than the barium chromate-manganese-sulfur delay powder.

Hydrogen Formation from the Magnesium-Moisture Reaction

The formation of hydrogen resulting from the reaction of moisture with magnesium powders plagued energetic compositions containing magnesium powder for a very long time. During 1944, Dr Hart of Picatinny Arsenal reported the dichromating of magnesium powders in igniter compositions for 37 mm tracer ammunition in order to reduce the undesirable formation of hydrogen. He coated the magnesium by immersion in a 5 percent aqueous solution of sodium dichromate and sodium hydrogen sulfate at room temperature. He stated that he found no earlier work to coat powdered metals. Up to that time, magnesium and aluminum fuels had been coated with linseed oil to provide protection and to serve as a binder of the composition. Dr. Hart observed further that the finer the magnesium granulation the more reactive with moisture, that the presence of strontium nitrate improved the resistance of magnesium to the reaction with water, and that sodium oxalate accelerates the reaction of magnesium with water.

Mr. Louis Lo Fiego of the Bermite Division, Whittaker Corporation Saugus California reported that in 1945 as one of his last duties as an officer in the U. S. Navy during World War II, he had the task to destroy unserviceable pyrotechnic items returned from the South Pacific. Black powder used in many pyrotechnic trains failed to ignite or sustain burning after being subjected to high temperature and humidities. In many cases the potassium nitrate in the black powder separated from the sulphur and carbon, forming beautiful crystals. This negated the usefulness of black powder as an ejection or ignition charge in pyrotechnics. Black powder delay trains were

found to burn erratically or not at all. Magnesium powder was found deteriorated because moisture reacting with the magnesium formed hydrogen gas, magnesium oxide and magnesium hydroxide. At the end of World War II, the general consensus was that the performance and reliability of pyrotechnics left much to be desired.

As reported in a 1951 report, Mr. Donat B. Brice of the Rockets and Explosives Department at NOTS conducted an evaluation of chromated magnesium powder as an igniter material and concluded that the potassium dichromate washed magnesium powder as an igniter component gave the same performance as observed previously with vinyl-coated magnesium powder. In this instance, the igniter material is a mixture of 50% coated magnesium and 50% potassium nitrate, by weight. This mixture was under consideration for use in igniters suitable for ignition of ballistite. Ballistite is a smokeless propellant made from two explosives those being nitroglycerine and nitrocellulose.

Starting work in August 1953, Mr. Ralph M. Moon, Jr. of the Rocket Department at NOTS, China Lake studied the evolution of gas from coated magnesium-black powder igniter mixtures. The Mk 125 Mod 2 igniter for the NOTS Model 103H 2.75-inch FFAR rocket motor developed sufficient pressure to burst the blowout disc. Mr. Wiebke of China Lake reported that a mass spectrographic analysis revealed that the gas released when the blowout disc yielded was 95% hydrogen. The hydrogen was formed by a reaction between the vinyl-coated magnesium and moisture in the black powder in the igniter charge.

Effectiveness Tests of Flares Against Missiles

In conjunction with WPAFB during 1955-1956, the Engineering Research Institute, Willow Run Laboratories at the University of Michigan conducted captive field tests of the Falcon GAR-1B air-to-air missile. They simulated the missile with a modified analog computer such as the one owned by the Eastman Kodak Company at that time. In the simulations, they considered dropped decoys, towed decoys, smoke, dust and blinking countermeasures.

Under a contract with WPAFB in 1957, Mr. Breymaier of the Willow Run Laboratories at the University of Michigan managed the dispensing of flares from the B-52 bomber and the B-47 bomber at Eglin Air Force Base to test their effectiveness against the Aerojet Engineering Corporation Aerowolf air-to-air missile, the Hughes air-to-air Falcon missile, and the Navy Bureau of Ships Atmospheric Sounding Projectile (ASP). Towed decoys and “blinking” techniques were also examined. Flare trajectories were determined by film reduction, a very tedious process. In 1958, the researchers declared, “The flare is the most important infrared countermeasure at the present time. Other countermeasures appear to have certain significant disadvantages. The most important characteristics of a flare are its infrared radiation intensity compared with the target, its trajectory relative to the target, and its burning time.”

In the early 1960s, Mr. H. L. Toothman and Mr. C. M. Loughmiller of the Naval Research Laboratory conducted decoy effectiveness tests of the Mk 46 (Mod unspecified but believed to be the Mod 0) flare against the ATOLL AA-2 air-to-air missile. The F-4B and the F-8 were the target aircraft. The test emphasized ejection direction and varying speeds with the objective of determining the optimum location of the flare launchers on the aircraft. Among their objectives was to evaluate flare parameters, which might allow flare redesign with proper radiancy and burning time. They recorded radiative intensity versus speed at launch and the degradation of power with increasing airspeed. They constructed a model using inputs from China Lake for the missile parameters and inputs from the Naval Research Laboratory of the atmospheric transmission in the infrared spectrum.

In 1965, Mr. E. S. Clemens and Dr. Edwards of the Air Proving Ground Center, Eglin Air Force Base reported radiometric measurement of the ALA-17 flare and the QRC-127 flare intended as penetration aids for the B-52 bomber. Both flares are compatible with the AN/ALE-20 dispenser and function at Mach 0.75 and at 35,000 feet altitude with 90% reliability. For radiometric measurements, they used a T-8 seeker, which is an Aerojet-General T-8 radiometer mounted in the nose of a B-47 bomber. The radiometer operates in two bands. The head includes a tracker (seeker) that uses FM track techniques as well as a radiometric capability. Both flares showed poor effectiveness in the 3.5μm to 5.5μm bandpass region but 100% effectiveness in the 2μm to 2.7μm bandpass region. The data from the T-8 seeker were extrapolated to the GAR-4A (AIM-9G) missile and with some success to the GAR-2A (AIM-4C) missile and the GAR-8 (AIM-9B) missile. The tests showed the importance of a fast rise time to peak intensity. The trajectory was satisfactory. Considering the difficulties of extrapolating data, they recommended that operational type seekers be used in future tests.

In 1970, the Operational Test and Evaluation Force (OPTEVFOR), at Norfolk Virginia evaluated the AN/ALE-29A dispenser and the Mk 47 Mod 0 flare. When deployed from the AN/ALE-29A dispenser of an F-4 aircraft or an F-8 aircraft operating at less than military rated power, the Mk 47 Mod 0 flare was found to effectively decoy the threat missile guidance system. Neither the F-4 aircraft nor the F-8 aircraft is adequately protected by the Mk 47 Mod 0 flare with afterburner operating.

In 1970, Mr. Harp and Dr. Handler of NWC China Lake tested the Mk 46 Mod 0 decoy flare at 25,000 and 50,000 feet simulated altitude and high airflow. They observed extremely reduced infrared output. They also flight tested preproduction Mk 46 Mod 0 flares and the EX 49 Mod 0 flares at 30,000 feet altitude against the AIM-9C Sidewinder missile. The flight tests were conducted during 1971 by VX-4 at Point Mugu. In addition, a flight test was conducted to determine the infrared effectiveness of Mk 46 Mod 0 flares when dispensed from an HH-1K aircraft. Mr. Harp also determined the effectiveness of the EX 49 Mod 0 flare as an infrared decoy. The China Lake team continued to define factors relating simulated and

actual flight test results. In addition, they initiated development of a facility for obtaining spectral measurements of flares under simulated flight conditions.

Comparative Flare Testing and Signature Measurements

In mid-1956, under contract to WPAFB, Eastman Kodak Company investigators recognized that infrared measurements were of primary interest although ultraviolet and microwave band measurements also needed to be considered. They measured flare radiative output at 10,000 and 40,000 feet altitude. They also measured the infrared signature of the B-47 bomber, the B-52 bomber and the B-66 bomber with an infrared scanner mounted in the nose of an RB-47 aircraft. In about the same time frame, efforts were being made to calculate the radiative output of rocket motors.

Mr. R. G. McCarty and Mr. H. Wair of NOTS, China Lake reported on the effectiveness of the NOTS Model 704 decoy flare against the Sidewinder missile in December 1958. Based on results from 1958 tests of infrared augmentation devices, the Air Proving Ground Center, Eglin Air Force Base conducted an evaluation to determine altitude effects on the TAU-15 flare performance. This occurred about 1960. Airborne flare measurements were accomplished at 30,000 feet from the instrumented B-47 aircraft flying in-trail with a B-57 bomber or T-33 aircraft towing a Del Mar Laboratory Radop TDU-4/B radar-reflective aerial tow target carrying the test flares. The tow target, equipped with four flare holders and a remote flare ignition system, was towed with 10,000 feet of cable. The measured radiometric data varied considerably. This deficiency was the basis for a further study to devise instrumentation and techniques to provide better measurements.

An early 1959 Eglin Air Force Base report describes ground and airborne infrared energy emission measurements of five aircraft and eight augmentation devices in the 1.8μm to 2.7μm bandpass region. Aerial measurements were made on T-33, B-57, RB-66, B-47, and B-52 aircraft to assess what type of augmentation device would be needed to simulate the aircraft signature. The infrared augmentation devices measured on the ground for radiant intensity versus burning time were the TAU-15/B (NOTS Model 711) flare, the T-245-3 flare, the W-211 flare, the USFC W111B flare, the Mk 3 Mod 0 (BB-9) flare, the W-211/A-5 flare, the UMC-94 flare and the UMC-95 flare. The TAU-15/B (NOTS Model 711) flare, the T-245-3 flare, the W-211 flare, the NOTS Model 702A flare and the Mk 3 Mod 0 (BB-9) flares were measured while airborne at 26,000 feet altitude and 175 KIAS. Depending upon the flare type at these flight conditions, the flares burned longer by 35% to 100% and the infrared intensity decreased by 10% to 30%. More detailed flare descriptions are in the FLARES DESCRIPTIONS section.

In 1961, Mr. Nichols and Mr. Sumnicht of the Aviation Ordnance Department at NOTS acquired five different types of flares from the Naval Astronautics and Missile Test Center, Point Mugu, California, all of which had similar dimensions though produced by different manufacturers. NOTS investigators made ground-to-ground

infrared radiation measurements of flares mounted on a 20-foot tower at an optical path length of 500 feet. The humidity was near 35%. The Denver Research Institute of the University of Denver provided infrared flares from contract AF 08-(635)-1402, Aerojet-General provided infrared flares given AF Part No. 60D-22348, Special Devices, Inc of Hughes Aircraft Company provided infrared flares given AF Part No. 60D-22390, and the US Flare Division of the Atlantic Research Corporation provided two flare types identified as the Model No. W204 and Model No. W205. All produced greybody type radiation with no specific emissions.

The Air Proving Ground Center, Eglin Air Force Base Aerojet-General, Armour Research Foundation of the Illinois Institute of Technology, Kilgore, Lambert Engineering, Picatinny Arsenal, and Universal Match Corporation developed the infrared countermeasure test devices under Air Force contracts.

In early 1963, some 1960 vintage TAU-15 flares failed to burn at 0.7 Mach and 35,000 feet altitude even thought the squib had fired successfully. The failures varied lot-to-lot, with altitude, and with the internal temperature of the individual flares. After the engineering investigation at the Air Proving Ground Center, Eglin Air Force Base, it was recommended that the TAU-15/B flare be replaced by an improved substitute.

Three different target flares, namely the W205 Lot 2 flare, the AGX0827 flare, and the TAU-56/B flare, were prepared for the Aeronautical Systems Division Detachment 4 at Eglin Air Force Base to be used in ground-to-ground and air-to-air tests. NOTS provided their locally developed color-wheel radiometer for radiometric measurements. Tests were conducted in the Air Test and Evaluation Squadron Four facilities at Point Mugu. The flares were mounted on a TA-7 aerial tow target manufactured by the Hayes Corporation and used in various forms by the Navy and the Air Force. They recorded burning time and effective radiant intensity in 0.5μm intervals in the 2.0μm to 6.0μm wavelength band while towing the target at altitudes between 5,000 and 50,000 feet at towing speeds of 0.5 Mach to 0.95 Mach.

There was a plan about 1964 to conduct high altitude and wind tunnel tests on a NOTS Model 729B augmentation flare and on a contractor developed Mk 37 Mod 0 flare used on the AQM-37A target drone. The parameters to be included in three related tests are (1) sea level, ambient conditions, and Mach 0.9, (2) 70,000 foot simulated altitude (33.6 Torr) at ambient temperature and Mach 2, and (3) 70,000-foot simulated altitude, minus 65 °F and Mach 2.

NOTS investigators extruded flare pellets, which were assembled into NOTS Model 715B target flares by the US Flare Division of the Atlantic Research Corporation. Twenty-four of these pellets were put in a circular drum of the AN/ALE-18 pneumatic chaff dispenser for test. Mr. Carter of NOTS in late 1963 reported ground-to-ground and air-to-air testing of these units.

Capt Lazarus Lebanoff USAF of the Air Proving Ground Center at Eglin Air Force Base described the measurement and evaluation of infrared flares in ground tests and flight tests at 20,000 to 30,000 foot altitude in a May 1964 report. The flares tested were the W205 flare, the W112B flare, the W211F flare, the TAU-15/B flare, the TAU-56/B flare and the AGC flare. All of these operational flares contain the magnesium-Teflon® composition. The scope of the tests included the determination of burning time and measurement of radiant intensity in both long and short wavelengths at sea level and at flight altitude. An additional purpose of this test was to derive a correlation between sea level and flight altitude flare performance.

Mr. R. E. Davis of ARO, Inc. reported on radiant intensity measurements acquired in March 1966 of two types of infrared flares. ARO, Inc. is a subsidiary of Sverdrup & Parcel and Associates, Inc. and is a contract operator of the Arnold Engineering Development Center, Arnold Air Force Station, Tennessee. The work was done at the request of the Air Force Armament Test Laboratory (AFATL) Research and Technology Division (RTD) Eglin Air Force Base Florida. Radiant intensity measurement from two types of pyrotechnic infrared flares over three wavelength bands were obtained at Mach 2.0 and Mach 1.75 and at simulated altitudes of 70,000 feet and 60,000 feet. The tests were conducted in the 16-foot supersonic tunnel. The flares were mounted on an AQM-37(A) drone missile installed in the tunnel test section. Testing consisted of radiometric measurements of flare irradiance over the wavelength bands of interest and subsequent determination of flare burning time. Results of the test indicate, especially for results at Mach 2.0 and in general for those at Mach 1.75, that radiant intensities and burning times of NOTS Model 729 flares were notably greater than corresponding results from Mk 37 Mod 0 flares. Radiant intensity measurements over all wavelength bands showed approximately twice the emitted flare radiant intensity at Mach 1.75 at an attitude of 60,000 feet as compared to radiant intensity at Mach 2.0 at an altitude 70,000 feet.

About 1966, the Aeronautical Systems Division at WPAFB sponsored a study at the Cornell Aeronautical Laboratory to review the performance of 28 decoy flares for the Penetration Evaluation (PENVAL) program, which encompassed the analysis and evaluation of tactical penetration aids.

In 1966, Mr. Craig Fenn, Mr. David Lyons and Mr. Edward Mattson of the Eastman Kodak Company conducted radiation measurements of rectilinear configured flares for the Aeronautical Systems Division at WPAFB. The Eastman Kodak team used a modified Perkin Elmer Rapid Scan Spectrometer Model 108 and a two-channel radiometer. No descriptions of the flares are given except to say that the flares were from the Illinois Institute of Technology Research Institute (3-types), Universal Match Corporation, Unidynamics, Central Technology Inc, and the Flare-Northern Division of the Atlantic Research Corporation.

In 1966, at the request of the Air Force, an Interservice Support Program was set up to perform acceptance testing and evaluation of the AN/ALA-17 flare at NOTS.

The tests were to be conducted in the NOTS 10 foot by 10 foot by 100-foot dark tunnel and the NOTS 16-foot diameter by 32-foot long altitude chamber.

A joint Air Force/Navy exercise was held at China Lake about 1966 to obtain airborne radiometric data, trajectories and functional capability of rectangular configured infrared flares, which were compatible with the USAF 669A Phase-I dispenser. The 2-inch by 2-inch by 5-inch flares were from four contractors. The Armour Research Foundation of the Illinois Institute of Technology provided the RR-115 flare, Unidynamics provided the UM-111 flare, Flare-Northern Division provided cast flares and Space Ordnance Systems provided the RR-119 flare.

About 1968, Mr. Claunch and Mr. Regelson of China Lake obtained infrared signature measurements of the A-4F, F-100, F-4C and OV-10A aircraft. In addition, Mr. J. Morris Weinberg of Block Engineering reported jet aircraft and missile exhaust spectra obtained by use of an interferometric spectrometer.

Under a 1968 contract, the Targets and Missiles Division of Eglin Air Force Base contracted with the Martin Marietta Corporation, Orlando Florida to determine the output of hybrid and selected pyrotechnic decoy flares. Mr. J. L. Durand and Mr. D. E. Sukhia of Martin Marietta took infrared measurements of a UTC hybrid flare, the W251 106E flare, the TAU-56 105E flare and the TAU-15 107E flare. They tested the units in a no-wind and wind environment, the latter being 50 to 60 knots. Their goal was to determine if these units could be used on drones carrying RF systems and to determine the compatibility between onboard RF and infrared systems.

In mid 1968, Mr. Breymaier, Mr. Hodge W. Doss and Mr. Yuji Morita of the Willow Run Laboratories at the University of Michigan conducted a flare study for ECOM at Fort Monmouth. They computed flare trajectories for those flares that would fit the AN/ALE-29 dispenser. Their objective was protection of UH-1, CH-47, and OV-1 type aircraft. They varied ejection velocities, speed, and ejection angles to determine zones of effectiveness.

Testing continued at NOTS of the Mk 46 Mod 0 flare and the Mk 47 Mod 0 flare at ambient and 20,000 feet simulated altitude, at 250 knots, and at 552 knots when ejected from aircraft. Both flares show greater radiant intensity in the 3μm to 5μm bandpass region than in the 2μm to 3μm bandpass region in static test at 2,500 MSL and at simulated altitude of 20,000 feet. They compared upward and downward ejection of the Mk 46 Mod 0 flare and Mk 47 Mod 0 flare for effectiveness against the AIM-9D Sidewinder missile.

Mr. Harp and Dr. Handler of NWC China Lake in 1970 conducted a thorough comparison of the Mk 46 Mod 0 flare with the Mk 47 Mod 0 flare. They concluded that neither the Mk 46 Mod 0 flare nor the Mk 47 Mod 0 flare could protect the RF4-J aircraft in military rated thrust from the Sidewinder 1C because the flares lacked sufficient infrared radiated power. However, protection of the RF-8 aircraft with these flares is satisfactory. In 1971 they reported tests of the Mk 46 Mod 0 flare as

a function of altitude and airflow in their high altitude simulation chamber in the 2µm to 3µm and 3µm to 5µm bandpass region. NAD Crane provided the flares for this test from a pre-production lot.

The spectral signature of the Mk 46 Mod 0 flare and the Mk 47 Mod 0 flare were measured in 1970. Mr. William Hyman and Mr. Lawaha Parrish of Army Missile Command Redstone made infrared measurements in 1973 of the Mk 46 Mod 0 flare and the XM-196 mini-flare. They measured the Mk 46 Mod 0 flare dropped from an A-4E aircraft at 400 knots and from a UH-1H helicopter at 100 knots. They also measured the XM-196 flare from the UH-1H aircraft at 100 knots and obtained infrared signature measurements of the aircraft during the same trials.

About 1970, Mr. Robert H. Roberts of ARO Inc. under contract to the Arnold Engineering Development Center, Arnold Air Force Station determined the separation characteristics of a TFAF flare from the F-4C aircraft at Mach 0.50 to 0.95. Infrared spectra were taken of both engines of the F-4C aircraft while in afterburner. Wind tunnel experiments were also performed at the Arnold Engineering Development Center, Arnold Air Force Station, Tennessee.

In the late 1970s, Mr. Persky of Block Engineering statically measured infrared spectral and spatial radiation from the ultraviolet and infrared regions of four flare formulae. Two formulae consisted of ammonium perchlorate, aluminum and a binder. The other two formulae consisted of Teflon®, ammonium perchlorate and a binder.

During May 1971, investigators of the Missile Electronic Warfare Technical Area, White Sands Missile Range New Mexico performed a series of experiments to determine the spectral radiant intensity of flares used with the Ballistic Aerial Target System (BATS). They made measurements at different aspect angles with flares fired in a static position.

During 1971, NWC China Lake investigators continued the evaluation of the Mk 46 Mod 0 decoy flare. They measured the radiant intensity at 380-400 knots and 25,000 feet altitude. Upon another occasion, they evaluated a preproduction lot of Mk 46 Mod 0 flares made at NAD Crane and EX 49 Mod 0 flares from MSL to 50,000 feet altitude at various airspeeds. At altitudes of 25,000 to 40,000 feet, the EX 49 Mod 0 flares burned about 2.6 seconds whereas the Mk 46 Mod 0 flares burned about 9 seconds. Both had serious ignition problems at altitude. The infrared power output of the EX 49 Mod 0 flare was considered to be too low. The EX 49 Mod 0 flare was tested from an F-4 aircraft at 30,000 feet to evaluate the ignition reliability.

In 1971 the Naval Air Systems Command asked China Lake to obtain infrared radiant intensity measurements of “scintillating flares” provided by Aerojet-General. Flares were measured in the 2µm to 3µm and 3µm to 5µm bandpass region using interference filters under ambient conditions and at reduced pressures simulating

altitudes from 7,500 to 40,000 feet altitude. The output fluctuated sinusoidally at 16-17 hertz. No data on the flare configuration or composition are available.

In 1973, EX 49 Mod 0 decoy flares were shipped to the White Sands Missile Range for extensive flare flight tests at altitudes of 1,500-6,500 feet above ground level and airspeeds from 230 knots to 600 knots. Later, in cooperation with the Agile missile and AIM-9L Sidewinder programs, flight tests of the EX 49 Mod 0 flares were to be conducted at 40,000 feet altitude to determine if the improved igniter performance previously observed at lower altitudes would be maintained at high altitude.

In 1973, the Aeronautical Systems Division at WPAFB requested China Lake to obtain infrared measurements of RR-119 flares at various altitudes to determine conformance with specification requirements. The RR-119 flare is compatible with the AN/ALE-28 dispenser in the F-111 aircraft. Flare-Northern/Celesco Industries provided contract flares for comparison with standard Air Force flares. Thiokol Chemical Corporation Wasatch Utah provided flare grains prepared by a cast method. Data were recorded from tests at ground level, 15,000 to 17,000 feet altitude and at 30,000 feet altitude in the 2µm to 3µm and 3µm to 5µm bandpass region. Later, Flare-Northern provided additional flares for evaluation at 70,000 feet altitude. The cast flares had a much lower infrared radiant intensity in the 3µm to 5µm bandpass region.

The Air Force at Hill Air Force Base in 1973 tasked Flare-Northern/Celesco Industries to evaluate eight flare racks from October 1968 and January 1969 production lots of AN/ALA-17 flare cartridges for possible extension of their service life. The tests were to include simulated altitude at 35,000 feet and 55,000 feet, burning time, and radiant intensity in spectral bands nominally covering the 2µm to 3µm and 3µm to 5µm bandpass region.

About 1973, Naval Air Headquarters asked China Lake to attempt to qualify a second industry source for infrared augmenters. NWC compared the infrared augmenter 3090N made by DynaTech Inc (DTI) to the Ballistic Aerial Target System (BATS) flare made by Flare-Northern/Celesco Industries.

By 1982, emphasis was to obtain infrared and performance measurements of production flares. Mr. Kenneth D. Meyer of General Dynamics Pomona was tasked to measure variations of the M206 flare and a production MJU-7/B flare. Variants of the M206 flare were: (1) an extruded grain containing ground magnesium, (2) an extruded grain containing atomized magnesium, and (3) production units. The MJU-7/B flare production units contained a pressed grain, as did one of the M206 flares. Power, trajectory, and spectra were obtained of the decoys launched from an M-130 dispenser mounted in a UH-1H helicopter operating at 60 knots and 120 knots.

Missile Countermeasure Techniques Development to Defeat Flares

Between August 1954 and November 1958, Aerojet-General conducted research on airborne infrared countermeasure techniques. The objective of that work is infrared detection and warning equipment for bombers. The design goal of the equipment is to detect air-launched, rocket-powered missiles at five miles or more.

The first field tests to determine the ability of a counter-countermeasure algorithm in the missile to discriminate against infrared flare decoys were initiated at NOTS in January 1961. Initial tests were conducted at ground level with captive flight tests following later that year. The ground tests results were in complete contradiction to the missile captive test results at altitude. This prompted Mr. J. F. Dibrell of the Bureau of Naval Weapons to contract with the Illinois Institute of Technology Research Institute for a study to determine the effect of air velocity on infrared flares. Dr. Raison and Mr. Richard T. Price of the Illinois Institute of Technology Research Institute conducted the work. The NOTS Model 704K target flare and the NOTS Model 704H target flare were used in the study. They concluded that air streams corresponding to those occurring in normal flight significantly reduce energy output from the flares on the order of a factor of ten in the spectral region between 1μm and 5μm. Previously, these reductions had been attributed to the reduced pressure at altitude. In 1963, NOTS investigators did improved discrimination techniques tests and more ground tests. Because of inconsistent and unexpected results, they decided to do more airstream tests as well.

Mr. E. J. Chatterton of Lincoln Laboratory Massachusetts Institute of Technology (MIT) reported a study of infrared modulation discrimination of flames and flares about 1962. He suggested that this feature might be used in a seeker to discriminate between different sources. He included flares consisting of magnesium-Teflon®-Kel-F® wax in the study.

Modeling and Simulation

Investigators at WPAFB in 1957 reported an analog simulation capability to estimate vulnerability reduction to the B-52 bomber by dispensing decoy flares from an RR-77 flare assembly housing. As modeled, the decoys were 3.5 inches diameter by 3.5 inches long and weighed 0.44 pounds.

During 1961 through 1964, Mr. Breymaier of the Willow Run Laboratories at the University of Michigan headed up a team that conducted simulation and analysis of infrared countermeasures for Mr. Sarnow of the Air Force Avionics Laboratory at WPAFB. They reported that simulation showed flares at missile launch or at preemptive launch gave good protection but noted that a controlled trajectory flare might be better. They also noted that a single free-fall flare gives good protection in the forward and rear hemispheres for considerable variations of target altitude and velocity. Their laboratory measurements showed that the required flare-to-target intensity ratio is a function of the target shape, seeker reticle design, angular

separation rate, and the rise-time of the flare intensity. The simulations included effectiveness consideration of the flare as a point source.

One of the tasks at the University of Michigan involved simulating the effectiveness of infrared flares against the GAR-2 Mach 4 missile, the latter having some frontal capability. The infrared seeking GAR-2 missile also known as the AIM-4B first appeared in 1956. One of the scenarios simulated was an attack of a Mach 3 aircraft at 30 degrees off nose at a 50,000-foot range. The work continued with the simulation of decoy flares against the GAR-8 (Sidewinder) missile and the GAR-K missile, the latter being a hypothetical air-to-air Mach 3 missile. Their interest was concentrated on protection of the B-58 aircraft from the forward hemisphere. In the evaluation, they used three flares called Type A flare, Type B flare, and Type C flare. The Type A flare and the Type B flare are 2-inch by 3-inch by 5-inch parallelepiped flares designed for gravity drops. The Type C flare, as reported in 1962, is a rocket-boosted flare that is fired forward from the aircraft. It has fins to provide aerodynamic stability. Initially, there is a thrust of 250 pounds for 0.5 seconds after which the unit is in free fall. All of the three flare types burn for about 10 seconds.

To determine the drag coefficient of burning flares, about which little is known in the early 1960s, Mr. Breymaier of the Willow Run Laboratories at the University of Michigan, used trajectory data from a flare launched from a rocket-boosted monorail sled test with a peak velocity of about 2,000 feet per second. The track is located at the Experimental Track Section of Edwards Air Force Base California. From these data, they calculated drag coefficients of the burning flare. Early information indicated that a flare has a high drag coefficient. Kilgore, Incorporated made the flares used for the trajectory experiments. The units were cylindrical, 5.75 inches long by 1.875 inches in diameter and weighed about 0.6 pounds. No known nomenclature for identification was assigned to these units.

In March 1968, Mr. Norman P. Quigley presented his MS thesis awarded by the Air Force Institute of Technology at WPAFB on a simulation study of an infrared countermeasure. He proposed a decoy with various parameters such as delay time, burning time, plume size and dual releases. He presented a mathematical model and simulated the decoy. He concluded that his proposed decoy could increase defense capability.

In 1968, Mr. Regelson of NOTS summarized the advantages and limitations of an infrared decoy flare. The advantages are: (1) ability to countermeasure simple missiles, (2) provides “point” targets, (3) has a small unit volume, (4) can be stowed in large numbers, (5) can be mass produced, (6) has low unit cost, (7) can fit existing stores and (8) is easily mounted on aircraft. The limitations are: (1) requires early warning, (2) increases visual detection, (3) require exact placement, (4) is susceptible to counter-countermeasure, (5) does not match target radiative wavelength, (6) is often unreliable at altitude, (7) requires special handling, and (8) requires a special dispenser.

Mr. R. J. Mador of Pratt & Whitney Aircraft division, East Hartford Connecticut reported a computer program for predicting infrared signatures.

Mr. Z. Newmark and Mr. J. Ratkovic of Hughes Aircraft Corporation Culver City California and Major H. C. Schlicht of the Air Force Avionics Laboratory at WPAFB developed and verified a mathematical model of the ALA-17 Flare, the Mk 46 (Mod unspecified) flare and a shielded flare. The team asserted that the IRCM community needed such a model because (1) no generic model was available, (2) flight test data were extremely limited, (3) flare intensity varies greatly with altitude and ejection speed, and (4) correlation between flight and static tests was found to be poor. With their model, they claim it is now possible to accurately predict the flare intensity profile for any ejection altitude, any speed, and in any spectral range. They reported a prediction of flare intensity profiles for altitudes from sea level to 40,000 feet, ejection speeds from 0.5 to 2.2 Mach and in five different missile-sensing bands. They made comparisons between measured and simulated profiles for the ALA-17 flare for several different flight conditions. Mentioned in a 1974 report.

APPENDIX

Earliest Record of Event or Concept

1929: Development of non-gaseous delay powders begins.
1931: First non-gaseous delay powder was developed. It was used in the M16-A1 primer detonator.
1938: Teflon® was discovered by Dr. Roy Plunkett of E. I. Dupont.
1943: Naval Ordnance Test Station, Inyokern, California is commissioned.
1944: First practical lead sulfide detector developed in the USA.
1944: First record that magnesium powder is dichromated for protection from moisture.
1949-1960: Towed aerial decoy concept is evaluated.
1950: Earliest record of addition of a fluorochlorocarbon (Kel-F® oil #10) to a binary mixture of magnesium and Teflon®.
1952: 14 May: First flight-test of EX 0 Sidewinder missile.
1953: Developed a method for increasing the burning rate of propellants by introducing good thermal-conducting high-melting metal wires such as copper into the composition: later known as staples or chaff.
1954: NOTS concerned with infrared target augmentation since 1954.
1954: The NOTS T-131 flare is the first infrared source for drone use.
1954: Started RITA flare development for bomber aircraft protection.
1954: Concept for Balls of Fire is introduced. This concept may have spawned variants such as the perforated can concept, shielded flare concept, wire mesh and annular-shielded flare concept and the jacketed flare concept.
1955: Made prototype of a Roman-Candle type pyrotechnic flare package.
1955: First addition of Kel-F® wax to a binary mixture of magnesium and Teflon®.
1955: First attempt to develop a pyrotechnic covert decoy flare.
1955: Noted that a showering action achieved a greater radiating surface area and that a showering flare was desirable because of the greater surface area that was radiating.
1955: Recognized that signature suppression is needed, which will enhance decoy effectiveness.
1955-56: Explored alternative decoy concepts such as dropped decoys, towed decoys, smoke and dust as an obscurant and blinking countermeasures.
1956: E. I. Dupont Company was the first to market Viton® A.
1956: Introduced Sidewinder missile into the US Fleet.
1956: Composition formulation 54% magnesium, 30% Teflon®, and 16% Kel-F® wax was discovered in the spring of 1956.
1956: NOTS Model 702 is the first application of a flare as a target tracking flare and is the forerunner of all IR flares. The composition consists of 54% magnesium, 30% Teflon®, and 16% Kel-F® wax.

1956: Jacketed-variant RITA Flares were housed in a perforated steel jacket. The perforated case design suggests similarity to the Balls of Fire or perforated can design concept wherein the flame spews simultaneously from all the holes in the surface of the flare case.

1957: Introduced concept of an inflated envelope decoy that could be used as a free or towed target. The resultant decoy would be a large-area extended-source with a low effective temperature.

1957: Infrared decoy flare development technology spread to the UK from the USA.

1958: NOTS Publication series of documents started.

1958: Development of a forward-launched/ forward-fired decoy concept was started. The concept was first proposed in 1954 during the Balls of Fire project.

1958: Started to develop concepts for infrared flares optimized to radiate effectively in the 3.0μm to 5.5μm bandpass region.

1959: First report of the Shock-gel process for making decoy flare composition.

1959: First replacement of Kel-F® wax with Viton® A in a magnesium-Teflon® formula. Prior to 1959, Kel-F® wax was the standard material added to a binary mixture of magnesium and Teflon®.

1959: NOTS Model 704A may have been the first countermeasure flare to have been developed.

1959: The W137 flare is one of the earliest magnesium-Teflon® formulated flares. It dates to before October 1959.

1960: The T-131 flare, the Mk 21 Mod 0 flare and the NOTS Model 702 flare are the most widely used tracking flares at NOTS.

1960: First record (5 July) of an infrared composition with the exact formula 54% magnesium, 30% Teflon®, and 16% Viton® A. First extrusion of this composition is 10 November 1960.

1960: NOTS Model 711A is first flare used for evaluation of weapon systems.

1961: The RR-82 flare cartridge has “pop-out” drag fins to partially control the trajectory. This design may have been the first so-called aerodynamic flare decoy.

1961: The first field tests to determine the ability of a counter-countermeasure algorithm in the missile to discriminate against infrared flare decoys were initiated at NOTS.

1961: Early attempts to make a large-area source flare, which would produce a large cloud of finely divided radiating carbon particles

1962: Earliest attempts to make infrared flares by the cast process.

1962: Flare tested which has a thrust of 250 pounds for 0.5 seconds after which the unit is in free fall: This may be the first trial of the kinematic flare concept.

1963: Attempt to develop a flare that would not be affected by windstream by adding a wire mesh shield in one case and in the other an annular shield with apertures to protect the combustion reaction from the windstream.

1964: The perforated-can flare concept (related to the shielded flare concept) was considered for incorporation into a forward launched decoy flare design.

1967: First attempt to create a pyrotechnic decoy that radiated in regions that correspond to radiative regions where aircraft radiate: spectral flares.

1967: Collected relative radiative intensity versus Mach number data, which probably was the first time such information was recorded.
1968: Recognized the need for 120-150 decoy flares on an aircraft operating in a dangerous area.
1968: First report that impact from 50-caliber projectiles can ignite magnesium-Teflon®-Viton® A compositions. This lead to the “bullet impact” safety requirement.
1968: The Mk 47 Mod 0, which entered production in 1968, is the first decoy flare designed for use in the AN/ALE-29 dispenser.
1968: Earliest record of attempt to generate infrared emissions from liquid pyrophoric fluids consisting of a mixture of 80% trimethylethylene (TME) and 20% triethylaluminum (TEA).
1969: Solid carbon is identified as the primary emitter in the typical decoy magnesium-Teflon®-Viton® A flare.
1970: Confirmed by designed experiment the marked reduction of infrared radiant intensity when flares are exposed to windstream. First time this characteristic of decoy flares was confirmed although the degradation had been noted for many years during tests.
1971: Stated that an area-radiating source is better than a point source.
1972: Roman Candle concept is advanced to make a flare using onboard fuel, gelling the fuel, followed by dispensing and igniting the gelled mixture as an infrared decoy.
1973: In the mid-1970s, the RR-119 flare (Later variant) was the highest performing flare in production.
1973: Attempt to develop a shielded flare to overcome flare performance degradation under high Mach windstream.
1974: NOTS Model 723 is largest MTV flare ever constructed: 12 inches in diameter by 16 inches long and weighs 70 pounds.
1974: Capability prediction that the FW355 flare, when used in conjunction with a missile-warning receiver, would give the FAC a fully automated IRCM system.

Origin of the Pyrotechnics R&D Department at NAD, Crane

The following are excerpts from a paper presented by Mr. Louis Lo Fiego Bermite Division, in July of 1982 at the International Pyrotechnics Seminar in Steamboat Springs Colorado. He reported that in 1946, the responsibility for the development of pyrotechnic items for the U. S. Navy was assigned to NOL White Oak, which by 1982 became a part of the Naval Surface Weapons Center. The responsibility for research in pyrotechnics and the development of pyrotechnic items for the U. S. Army was assigned to Picatinny Arsenal, Dover New Jersey, which by 1982 evolved into the Army Research and Development Command. The Chemical Warfare Group at Edgewood Arsenal was responsible for screening and colored smokes. The Air Force depended on the Navy and Army for its pyrotechnic needs. During that period Dr. Hart, Head of the Chemical Research at Picatinny Arsenal made immeasurable contributions in advancing the state-of-the-art in pyrotechnics by innovative program planning and implementing these programs through talented personnel.

Mr. Lo Fiego goes on to say that a respected Army General, on his return from World War II stated that there would be no need for pyrotechnics in future wars because electronic and mechanical devices would replace pyrotechnics. Exceptions were photoflash bombs and smoke producing devices. The net result was that financial budgets established for pyrotechnic programs for 1946 through 1950 were minimal. Personnel in Government involved in pyrotechnics felt that in order to establish respect for their work, efforts should be directed toward meeting three objectives: (1) establish real and new needs for pyrotechnics, (2) develop pyrotechnic devices that would be considered ordnance items rather than fireworks, and (3) convert pyrotechnics from a black art to a science. The Navy’s Operational Development Force at Boca Chica Florida while developing tactical procedures for Anti-Submarine Warfare (ASW) operations established a need for new aircraft parachute flares and marine markers to satisfy ASW requirements. This helped to reestablish important Navy pyrotechnic programs, which, for example enabled the development of the Mk 24 Mods series aircraft parachute flares. In addition, funds were provided to investigate and develop new and more reliable pyrotechnic compositions.

In 1947, the Navy planned to close the facilities for manufacturing pyrotechnic items at NAD Crane. This is the pyrotechnic production facility at Crane that was built during World War II to continue the production jobs that were transferred from the Navy’s Baldwin Long Island pyrotechnic production plant when it closed in the early 1940s. Pyrotechnic administrative personnel in Washington DC Headquarters, who include Mr. Lo Fiego, convinced the Navy to maintain the production facilities at NAD Crane. This was accomplished by using development funds to employ and keep the key people at NAD Crane who had many years of experience in manufacturing pyrotechnics. As an example, the design work for a new illuminating projectile was accomplished at NOL White Oak and the prototypes were fabricated at NAD Crane.

Not losing these individuals proved to be very fortunate for the USA during the Korean War. Casualties were high in South Korea because of night infiltration by the North Koreans. As a result, the U. S. Air Force requested the Navy to produce and deliver as many aircraft parachute flares as possible to this area. The pyrotechnic personnel at NAD Crane met the challenge resulting in a letter of commendation from the Air Force. In essence, the letter stated that the flares permitted interdicting the enemy's advances and were instrumental in not losing the war in Korea. The letter helped the cause of pyrotechnics and was used to justify additional funds in the Navy's budget.

The staff in the Navy Headquarters was instrumental in establishing a group of technical personnel at NAD Crane for the production engineering of newly developed pyrotechnic devices. Later this group became the research and development arm for Navy pyrotechnics and deserves credit for helping advance the state-of-the-art and for developing items that are in the category of reliable ordnance items. Eventually, about 1955-1956, that group became the nucleus of the Pyrotechnics Research and Development Department at NAD Crane starting with a complement of about 20 persons.

Origin of the Technology Base for U. S. Military Pyrotechnics at Picatinny Arsenal

Before WW II and after WW II in 1946, the state-of-the-art of pyrotechnics was not in good shape. Pyrotechnics was still an art and not a science. About 1947 at Picatinny Arsenal, there was a surge in armaments research and development caused by the technical and tactical shortcomings experienced on the battlefield. At that time, funding for pyrotechnics almost did not exist. This started to change in 1947-1948 when materiel development requirements by the newly established U. S. Air force, formerly the U. S. Army Air Corps, became a dominant factor. The U. S. Air Force was largely dependent for its ordnance upon U. S. Army Ordnance and in turn on the Army's arsenals and laboratories. At Picatinny Arsenal, this created a requirement for pyrotechnic munitions such as aircraft illuminating flares, rescue and distress signals, and photoflash bombs and cartridges for night aerial photography.

At Picatinny Arsenal, the pyrotechnics research, development, and engineering missions were executed within the Technical Group, subsequently renamed the Technical Division. Later, the Technical Division was renamed the Samuel Feltman Ammunition Laboratories and subsequently the Feltman Research and Engineering Laboratories. The latter continued to exist until the summer of 1960. Reorganization of the Technical Group into the Technical Division just prior to 1950 resulted in the elimination of major Branches and established Assistant Division Chiefs in four functional areas.

In January - February 1950, the Technical Division was reorganized again. The result was that Mr. Abraham L. Dorfman became Chief of Development and Engineering, Dr. David Hart became the Chief of Chemical Research, and Mr. Henry Eppig became Chief of Physics, Instrumentation and Testing. In late 1950, Mr. Dorfman became Chief of the Technology Division and Mr. Henry Cohen replaced him as Chief of Development and Engineering.

A major obstacle was the lack of sufficient funds for pyrotechnics research and technology. To overcome this obstacle, Mr. Dorfman chose to internally tax the well-funded hardware development and engineering projects and to use the accumulated funds for pyrotechnics research and technology. Without these research and technology funds, the U. S. Army's materiel advances in military pyrotechnics would have been minimal. All through the 1950s and into the early 1960s the Pyrotechnics Laboratory at Picatinny Arsenal was the sole research center among the U. S. Armed Services.

Mr. Dorfman writes that the presence of technical managers who perceived the absolute need for a sound technology base; the decision to start on the long road towards eventual realization; the conviction that hardware requirements could not

be met without a substantial investment in technology; and the availability of heavily funded hardware development projects that could be judiciously used for this purpose made the 1950s the crucial formative years for military pyrotechnics in the United States.

A Brief History of Military Pyrotechnic Research Facilities in the United Kingdom

The UK facility[11] for military pyrotechnic research and development first commenced at Woolwich Arsenal, and was then built up to meet the pyrotechnic requirements of the First World War. One of the Woolwich scientists who was central to the development of UK military pyrotechnics was Mr. Jack C. Cackett who was known as "The father of UK pyrotechnic compositions". With his team, Mr. Cackett built up the knowledge on UK fuel/oxidant mixtures and how to apply their properties to meet increasingly difficult military requirements. Since the First World War these compositions were detailed and registered in the Superintendent of Research (SR) Composition Book. These "SR Compositions" were widely used by many NATO countries.

In 1940, following the outbreak of the Second World War, the pyrotechnics research group was evacuated from Woolwich to the grounds of Tondu House in South Wales. This was situated near to the military ordnance production factory at Bridgend. At this time Tondu was known as the Armament Research Department. (ARD) and was controlled by the Headquarters Establishment at Fort Halstead, near Sevenoaks in Kent

In about 1957, the pyrotechnics facilities at Tondu were moved to Langhurst near Horsham, Sussex. Initially, Mr. Jack Cackett was the senior scientist in charge of the pyrotechnics team, which was made up of very experienced scientific and technical staff, who had transferred with him from Tondu. The research facility was an outstation of Fort Halstead, which in February 1962 was called the Royal Armament and Research Development Establishment (RARDE).

At Langhurst the pyrotechnic facilities and supporting scientific, engineering and technical staff were increased in order to meet the complex technical requirements for pyrotechnics in modern warfare. It was at Langhurst that Mr. Cackett wrote his book titled *Monograph On Pyrotechnic Compositions* originally classified to a restricted circulation but is now unclassified. The date of this publication is January 1, 1965.

During 1976 and 1977 Langhurst was closed down and all the pyrotechnic research and development facilities were transferred to RARDE, Fort Halstead.

During 1993, RARDE, along with other UK research establishments became the Defence Research Agency (DRA). In 1996, DRA became the Defence Evaluation Research Agency (DERA). In April 2001 two organizations were formed from

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[11] Dr. Tony Cardell OBE provided these details. He joined Mr. Jack Cackett's team at Langhurst in 1962 and worked on UK pyrotechnic research and development through to his retirement from QinetiQ in 2004.

DERA. One is the Defence Science and Technology Laboratory (DSTL), which is part of the Ministry of Defence and the other is the public limited company, QinetiQ.

History Of Navy Pyrotechnics Evolution

An Interlaced Account of My Pyrotechnics Career at Crane

Prior to and during World War I, private contractors did nearly all pyrotechnic manufacturing and development work for the Army or Navy. During World War I, the Navy had a contract with the Ordnance Engineering Corporation, 120 Broadway, New York City, for the manufacture of 3, 4, 5 and 6-inch illuminating projectiles. That company held patents covering this type of projectile. The Ordnance Engineering Corporation began operations in an old farmhouse, located on what is now (1957) Sunrise Highway, Baldwin, Long Island, New York. A major fire destroyed the facilities after a few months of operation. [12]

In 1918, the Navy constructed a new plant in Baldwin, Long Island on Milburn Avenue for the Ordnance Engineering Corporation to use in the development and manufacture of illuminating projectiles. At the termination of World War I, the plant was taken over and operated by the Navy as the United States Naval Ordnance Plant (NOP), Baldwin, Long Island, New York. Its one product was illuminating projectiles until 1930.

Then, the plant was awarded a small contract to manufacture Naval aircraft parachute flares. Baldwin collaborated with the United States Naval Ordnance Laboratory (NOL), Washington, D.C., in the improvement and production of the Mark 4, Naval Aircraft Parachute Flare. Sixty units per week was the average schedule until 1939. From 1938 to 1942, the Marks 5 and 6 Aircraft Parachute Flares were developed and produced through the combined efforts of NOP Baldwin and NOL Washington.

NOL Washington was located in the Naval Gun Factory at the Navy Yard along the river in the SE section of Washington DC. NOL Washington did not become established in Silver Springs, White Oak MD until 1943. The latter became known as NOL Silver Springs and, today, is better known as NOL White Oak. (About the year 2000, it was closed by BRAC)

The working force for the Baldwin Plant was reduced to as few as 125 persons shortly after 1930. Private manufacturers were doing some development and manufacturing of pyrotechnics, but the quantities were small. The status of naval pyrotechnics as World War II began was similar to the status of military pyrotechnics at the beginning of World War I: somewhere between lousy and terrible! The demand for pyrotechnics was much greater and more exacting during World War II than during World War I because of the improved implements of warfare.

[12] Morecock, William R. and George A. Platz, Jr. *Naval Pyrotechnics Development* 1957, prepared for NAD Crane. Some of the early information was extracted from this document. AD0003349.

Expansion had to be great. Contracts were let with companies who had no experience in this field. Experienced people had to be spread thinly over the industry to form nuclei for production units. Substitute materials had to be tested and authorized. Old units had to be improved and new units had to be designed. The production capacity of the Baldwin Plant was increased 900% from 1939 to 1942.

In the 1930's and 1940's, pyrotechnics development was assigned to the Naval Ordnance Laboratory, Washington DC. When NOL Silver Springs was established in 1943, the pyrotechnic development effort was transferred there. At NOL Silver Springs, Mr. Bernie White, Mr. Louis LoFiego, Mr. Dean Jensen, Mr. Roscoe Dwiggins, and others, did pyrotechnics development. They worked on projects sponsored by the Bureau of Ordnance (BuOrd) Washington, DC. NOL White Oak had laboratory facilities but only limited capability to build developmental and demonstration pyrotechnic test items.

BuOrd was located in "temporary" buildings built in World War I in Washington DC on the NW end of the Mall, just North of the Reflecting Pool. Also located in the vicinity, just to the South, were temporary World War II buildings occupied by BuAir and others. BuOrd had counterpart Bureaus such as BuAir, BuShips, BuDocs, BuMed, etc. BuOrd had charge of all ordnance including all Naval pyrotechnics. BuOrd section Ma3-b was the production-oriented group. Ma3-b later moved to NAD Crane to become NAPEC, Naval Ammunition Production Engineering Center, headed up by Mr. Art Maas. The Re2-a section of BuOrd sponsored research and development and ReW3c was the Pyrotechnic group of BuOrd. BuOrd moved to Crystal City, Arlington VA about 1962-3 when the old buildings on the Mall were torn down.

In 1940, the Bureau of Ordnance (BuOrd) decided to build a new pyrotechnic plant of larger capacity than at Baldwin at the Navy's newly constructed East Coast Ammunition Depot, Burns City, Indiana. At this location, the Navy was building facilities to load, renovate, and store naval gun ammunition such as the 3/50, 5/38, 6/47, and 16 inch projectiles and associated cartridges, bombs, torpedo warheads, depth charges, naval mines, and other conventional ammunition categories but not munitions containing propellants such as rockets. This depot was later renamed U. S. Naval Ammunition Depot (NAD), Crane, Indiana. A plan had existed for years to construct a new Star Shell Plant (illuminating projectiles were known as Star Shells) at the Naval Powder Factory, Indian Head, Maryland. That plan was jettisoned and the new Pyrotechnic plant was built at NAD Crane. Mr. William Russell Morecock, aka Russ, Mr. Jim Palladino and a few others came from Baldwin to run and staff the new pyrotechnic plant. Mr. Morecock was the Master Mechanic of the new operation, which today (2002) is the fenced in area near Building-120 (B-120). He also was the Master Mechanic of the Baldwin plant. He claimed to have had a hand in the design and layout of the new plant at Crane.

The Pyrotechnics Production Division of the Ordnance Department at NAD Crane, BuOrd, NOP Baldwin, and NOL Washington cooperated in the research and development of new pyrotechnics and the improvement of old pyrotechnics during World War II. After the war, NOP Baldwin was deactivated, practically all-private manufacture of pyrotechnics was discontinued, and NAD Crane's pyrotechnic production personnel staff was reduced to about 100 employees.

Mr. LoFiego writes that in 1947, the Navy planned to close the Pyrotechnic Production Plant at NAD Crane, which manufactured pyrotechnic items. He states “we” were able to convince the Navy to maintain these facilities. This was accomplished by using development funds to keep the key people who had years of experience in manufacturing pyrotechnics. As an example, the design work for a new illuminating projectile was accomplished at NOL Silver Springs and the prototypes were fabricated by NAD Crane Ordnance Department. Not losing these key individuals proved to be very fortunate for the USA during the Korean War.

Many World War II pyrotechnic items showed exceptionally poor performance ability after two or more years of storage. The Navy also appreciated the necessity of new designs for pyrotechnics to keep pace with aircraft that fly higher and faster and submarines that descend deeper. These requirements resulted in the Navy’s instituting a research and development program for existing and new pyrotechnic items. Much of this work after World War II was carried out in collaboration with NOL Silver Springs and a limited number of private contractors first by the Production Division of the NAD Crane Ordnance Department until about 1951 and then by the Research and Development Division (R&D Div) of the Ordnance Department at NAD Crane until mid-1956. By this time, liaison was well organized between those groups, which use pyrotechnics, and the groups that design and manufacture pyrotechnics. The Bureau of Ordnance established budgets and planned projects to keep pyrotechnics abreast of the other tools of war that were being devised.

Before NAD Crane existed, NOL Washington got support from NOP Baldwin. When NOL Silver Springs and NAD Crane came into existence about the same time, NOL Silver Springs came to the NAD Crane Pyrotechnic Production Plant for support, first directly to Mr. Russ Morecock in the production plant and later to the R&D Division of the Ordnance Department at NAD Crane. Then when the Research and Development Department was established at NAD Crane in 1956, NOL Silver Springs received pyrotechnic design support from NAD Crane’s new Research and Development Department.

NOL Silver Springs would come to NAD Crane by work request to get models and test units made to their designs during the early 50’s (the Korean war era) and perhaps earlier. Mr. Glen Casey, Jr. known only as “Casey”, pyrotechnics tool and die maker in the pyrotechnics plant, worked with Mr. Bernie White during his visits to NAD Crane to work out the details. The units or components were sent to NOL

for test. After testing, the cycle repeated again and again. This effort was supported at NAD Crane by a small R&D Division of the Ordnance Department, which was made up of about 6-8 Navy Ensigns and LTJG's headed by a reserve LCDR Austin Behlert USN who reported to the Ordnance Officer CDR John Ela USN. The Commanding Officer at that time was CAPT Eugene C. Rook USN. The pyrotechnics development and the NOL work was administered and directed by personnel of the Pyrotechnics Division. These persons worked with Mr. Russ Morecock and his Pyrotechnics Plant personnel to get the work done.

Bernard E. Douda was one of the Navy Ensigns sent to NAD Crane in September 1952 to work in the Pyrotechnics Division of the NAD Crane Ordnance Department. Others were: Mr. Joe Hammond, Mr. Bob Mariman, Mr. Roger Struck, Mr. Dick Randall, Mr. Bruce Butrym, Mr. Jim O'Brian, and Mr. John Dimmer. Mr. Hammond eventually became the administrative assistant to the Ordnance Officer. Mr. Dimmer engineered the production set-up and initial operation of the Plaster Load Facility in Building 2084 to fill warheads with an inert material for training use. Mr. O'Brian was our Explosive Ordnance Disposal Officer (EOD) assigned to run the EOD Demolition area. Mr. Butrym hooked up with the Special Projects (SP), ADM Rickover area, converted to regular Navy, and eventually achieved Captain's rank and, as his last duty station (I think), served as the Commanding Officer of the Navy Weapons Station (NWS) at Charleston, SC.

Trying to conduct developmental projects remotely from NOL White Oak was cumbersome. NOL White Oak was not very interested in the small amount of money, which pyrotechnics brought in. By this time (about 1954) Mr. LoFiego transferred from NOL White Oak to BuOrd to head up the pyrotechnics group there. Mr. Stan Fasig, a young engineer and Mr. Phil Smith (aka PJ) started to work at NOL White Oak, both on the same date. Mr. Ray Szypulski also was an NOL employee. NOL White Oak and BuOrd chose to move pyrotechnics R&D to Crane. To do this, they set up 19 billets at NAD Crane. With the support of Command and the Civilian Personnel Office, Mr. LoFiego came to NAD Crane for a week. He and then LTJG Douda, using NOL White Oak Position Descriptions (PD's) for samples, wrote the 19 PD's for the new NAD Crane R&D Department. Staffing started in late 1955 and early 1956. Mr. LoFiego later left government service to join the Bermite Powder Company in Saugus CA where he had a senior position, such as General Manager. Later, Mr. Fasig and Mr. Smith transferred to NAD Crane to fill positions in the new R&D Department.

In April of 1956, a Pyrotechnics Research and Development Department was established at NAD Crane for conducting all new pyrotechnic design through the prototype production for evaluation (PPE) stage. In this stage, new designs are subjected to a "dress rehearsal" production and the design or tooling are altered to achieve a product which will function to specifications and can be fabricated by conventional methods of manufacture. In today's terminology, we might think of the PPE stage as a late phase of Engineering Manufacturing Development (EMD) or an early phase of Limited Rate Initial Production (LRIP).

Mr. Victor Willis, then at Aerial Products Company, Elkton MD was chosen by Mr. Russ Morecock and Crane's Command as the first Pyrotechnics Research and Development Department Director of NAD Crane. Soon to follow Mr. Willis from Aerial Products was Mr. Ben Harkness. While still in the military, LTJG Douda was assigned to head up the Chemical Engineering Division of the R&D Department. In May 1956, LTJG Douda was released from the military and continued in the job as a civilian. Mr. Phil Cornwell, a Mechanical Engineer, was hired from Fabricast in Bedford, Indiana, a GM foundry operation. Mr. Stan Fasig was soon hired as the Mechanical Engineering Division head and very soon befriended Mr. Willis and moved into his office to become the Deputy Director. Mr. Phil Smith had transferred from NOL White Oak to BuOrd and then was hired by NAD Crane in early 1960 to form an Evaluation Division. Mr. Phil Cornwell became the Mechanical Engineering Division head. Mr. Charlie Connor headed the Documentation Group, of which Mr. Noble Wittenmeyer and Mr. Paul Scott were senior members. Mr. Wittenmeyer was a draftsman and Mr. Scott did a lot of design work as a draftsman. Mr. Jerry Kemp hired in as a Mathematician and soon headed the Math/Statistics Division. To this nucleus of staff came the duties of pyrotechnics development for the Navy. By 1958, NOL, White Oak had phased out of pyrotechnics development completely.

The R&D Department set up offices in the upper deck of Building 38 about late 1955, had no lab space there, and thus had to use the facilities of the pyrotechnics production plant for prototype operations, both mechanical and chemical. After about two years, Building 198 and Building 2540 were made available for the R&D Dept. (estimate 1958-9).

Several devices the R&D Department personnel were working on in the early 50's (about 1953) were the Mk 7 Mod 2 Marine Location Marker, the Mk 5 Mod 4 Marine Location Marker, Submarine Emergency Identification Signal (SEIS), and others. They were working on improved models of these devices. The Mk 25 Mod 0 Marine Location Marker came out of this effort about 1958.

About 1955, a red phosphorus (RP) production capability was built inside the pyrotechnics plant area. Mr. Morecock was still the Master Mechanic. He later retired about 1956 with severe health difficulties. LTJG Douda was Pyrotechnics Officer, assigned by CDR John Ela, to oversee the pyrotechnics operation for the Ordnance Officer. The RP area had many daily fires, mainly in the mixing and pressing operations. Three to six fires per 24 hours were not uncommon. LTJG Douda had the assignment of chasing the fire engines day and night. As we learned how to handle RP safely and improved the processes and procedures, fire and injuries diminished to a rarity.

About 1957-8, NOL White Oak and BuOrd wanted a second source for thermal battery production, then being produced by Eureka Williams and Eagle Pitcher. We visited the plant to learn how to build the battery and proceeded to build a thermal battery production line inside Building 2698. Some operations were technically

difficult because of the need to operate at about 4-5% relative humidity and the need to control the energy of the heat paper very closely. A lithium compound, which was extremely hygroscopic, was a major component of the heat paper. It required very low humidity during processing. A Parr Bomb calorimetry room was set up to do the heat paper analysis. Mr. Clarence Gilliam conducted a lot of the heat paper calorimetric measurements.

During the Korean War period, pyrotechnics production and development was booming. BuOrd later reorganized to become the Bureau of Naval Weapons (BuWeps), and still later to reorganize and split to become Naval Air Systems Command (NAVAIR) and Naval Sea Systems Command (NAVSEA). These agencies started to assign NAD Crane pyrotechnics duties such as Cognizant Field Activity (CFA). We were assigned all NAVSEA pyrotechnics and most of NAVAIR pyrotechnics responsibilities. A block of research money flowed from the Office of Naval Research (ONR) to NAVAIR and NAVSEA for them to administer and direct toward their special interests. We eventually received some of these research funds from NAVAIR, administered by Dr. Hyman Rosenwasser. Exploratory development funds were distributed in a similar manner: in NAVAIR Mr. Dick Wasneski, Mr. Jerry Kovalenko, LCDR Hugo Hardt and others and in NAVSEA by Dr. Adolph Amster and Mr. George Edwards. OPN and hardware development funds were administered in NAVAIR by Mr. Ray Szypulski as Technical Agent for PMA-253/PME-107, the latter being the REWSON (electronic warfare) Office of the Naval Electronics Command (NAVELEX).

It was during most of the 1960's and the early 1970's that NAD Crane received research and development funds from NAVAIR. About mid-1960, non-infrared (IR) decoy funds started to go away both in NAVAIR and in NAVSEA. The NAVSEA emphasis was on pollution abatement and disposal. For about ten years, we developed processes for ecologically acceptable ways to dispose of all categories of pyrotechnics. Dr. Ken Musselman and Dr. Carl Dinerman did most of the exploratory work and Mr. Jim Short developed pilot plants for these processes for NAVSEA. By about 1972, except for the disposal work, NAVSEA was out of the pyrotechnics development business. NAVSEA was assigned the tri-service lead for energetic materials disposal and pollution abatement.

In the early 1960's, NAVAIR set up the Naval Weapons Station, (NWS) China Lake to administer the pyrotechnics exploratory block of funds. NAD Crane then had to obtain NAVAIR pyrotechnics development funds from NWS China Lake. The latter tended to favor funding their projects in preference to projects proposed by other activities. They were chosen for this lead, instead of NAD Crane, because they were a NAVAIR station and NAD Crane belonged to NAVSEA. NAVAIR could not see fit to appoint a NAVSEA station to administer their work. This lasted until about 1977. When the amount of funds had diminished to below a critical mass, NWS China Lake told NAVAIR they would get out of the pyrotechnics development business entirely. FY 77 was the last year which NWC China Lake controlled the

exploratory development funding block and by 1980 had quit the pyrotechnics business completely.

In the early 1950's, the Naval Ordnance Test Station (NOTS), China Lake had embarked on the development of a heat-seeking missile, later to become the Sidewinder, AIM-9 series. This effort was lead by Dr. William B. McLean. He eventually became the NOTS Technical Director. In addition, there was substantial activity in development of devices against which the Sidewinder could be tested. In the early period, long before there was a need to determine the effectiveness of the Sidewinder against airborne targets, target flares and tracking flares were needed to make it easier to test rockets and missiles. Early tracking flares were formulated to produce visible radiation for visible tracking, presumably because tracking technology in the infrared was non-existent. Under the leadership of Dr. George Handler at China Lake, infrared target and tracking flare development and later infrared decoy flare development work continued into the 1960's. Dr. Handler, Mr. Art Breslow, Mr. Ed Allen and others lead this work. Their team and laboratory dissolved about the time (1960) that NAVAIR appointed NWC China Lake as the pyrotechnics lead. Dr. Handler has retired, as has Mr. Breslow. Mr. Allen transferred to NAVAIR to work for Mr. Szypulski and then to NAD Crane for a short period.

About the same time period (1964-1975), the Vietnam War was in full swing. As mentioned earlier, pyrotechnics funds for non-decoy projects were terminated first in NAVSEA about 1973 and then by NAVAIR about 10 years later. This left infrared decoy work as the first and only priority. Non-decoy pyrotechnics continued as product improvement, malfunction investigations, and production support. The demand for infrared decoys during the Viet Nam war was critical. PMA-253 and Mr. Szypulski pushed hard to get infrared flares developed and tested. NWC China Lake received substantial funding for decoys in the mid- to late-1960's. Mr. Don Hazelton of NAD Crane became involved with Dr. Pierre St. Armand of NWC China Lake for the development of a weather modification expendable based on silver iodide. These were tested during the hurricane season to try to reduce the fury of the storm. The units were fitted into the photoflash dispenser. Mr. Hazelton used his experience with the weather modification expendables development and his contacts in PMA-253, NAVAIR, and at NWC China Lake to ease into infrared decoy development. With only modest funding from PMA-253 via NAVAIR (Szypulski), Mr. Hazelton prepared infrared decoy test units for test first at NAD Crane and then for air test at NWC China Lake. The start of production of the Mk 46 Mod 0 took place during 1968 at NAD Crane. In response to a May 1972 Fleet message from Viet Nam expressing an urgent need for infrared decoys, NWC China Lake took the N-35 propellant (MTV-also called composition PL9001), put it into the pyrotechnic pistol cartridge and made the Mk 50 Mod 0 decoy flare for the M8 Pistol. The decoys were tested for decoy effectiveness using the Redeye missile as a surrogate for the SA-7 threat missile. Two thousand infrared decoys were shipped to SE Asia in June 1972. A recommendation for release to unlimited production of the Mk 50

Mod 0 decoy flare was issued 30 October 1973. Production followed of 50,000 units at the Naval Ordnance Station (NOS) Indian Head MD.

During this time period, Mr. Douda was doing research for Dr. Rosenwasser of NAVAIR and also attending Indiana University studying for a PhD in physical chemistry. (1973). Also in this time period, the R&D Department had a Chemistry R&D group doing development, first during the period that NAVAIR funded Crane directly, then during the period that NWC China Lake managed the funds for NAVAIR as non-decoy work faded. Eventually, NWC abandoned pyrotechnics development leaving it mostly for NAD Crane. This covered the 1960's. About 1968, Mr. Szypulski was contemplating retirement and while visiting NAD Crane, tried several times to persuade Mr. Douda to transfer from doing research and development to taking over the coordination of the decoy work as technical agent for NAVAIR and PMA-253. He wanted to transfer the focal point for this from NAVAIR to NAD Crane by way of a Transition Agreement. In this way, he thought his efforts would be continued. In February 1976, Dr. Douda was appointed DAPM, Deputy Assistant Program Manager to NAVAIR to lead the decoy work. By this time, Mr. Hazelton had solidified himself and NAD Crane in the decoy business. As DAPM, and with Mr. Szypulski still in NAVAIR for about a year more, Dr. Douda was taught how to deal with NAVAIR and PMA-253, how the money was structured, and how to sell projects to PMA-253. Mr. Szypulski retired at the end of 1977 and went to North Carolina to help his son in business.

Crane proceeded to formulate long-range infrared decoy development plans and propose them to PMA-253. CAPT Don Mathews was in charge. Mr. Bernie Panella was the Deputy. Mr. Panella and CDR Walt Carlson were decoy flare proponents. CDR Carlson later was in charge of the ASPJ project and still later would form and head up a PMA for the ASPJ. Mr. Panella retired about 1979 to form his own Electronic Warfare (EW) Company, now known as Raven, Inc. The new Deputy (about 1979) was Mr. Tony Grieco, not a decoy flare proponent, who later would leave to take the top EW job in the Office of the Secretary of Defense (OSD) when Mr. George Nicholas retired. Dr. Bill Goodell came to PMA-253 from the Naval Research Laboratory (NRL) to head up the Electro-Optics (EO) efforts. For OPN funds, we worked in PMA with Mr. Stan Bender starting about 1970 with the guidance of Mr. Szypulski and later alone after Mr. Szypulski retired about the end of 1977. For development funds, we worked with CDR Carlson, now retired and operating his consulting company, and Mr. Panella in the early 1970's and later with Mr. Frank Daspit starting about 1977.

Several events made our job more difficult selling decoys to the Program Office. In the late 70's, Mr. Panella and CDR Carlson left. The Navy was reorganizing again. PMA-253 was separated from PME-107. Mr. Goodell died in a car crash about 1985. Mr. Tony Grieco became Deputy in PMA-253 (retired about 1 April 2002). About 1994, Mr. Bender left PMA-253, went to NOP-88 Requirements, and about November 1995, went to the Ballistic Missile Defense Office BMDO. Mr. Bill Rock took over for expendables in PMA-253 when Mr. Bender left. Of all the managers in

Washington DC, Mr. Bender was not only a strong proponent for infrared decoys but also was a staunch supporter of NAD Crane throughout the years.

With the many organizational and personnel changes in Washington DC, we at Crane often were left without experienced decoy flare proponents in PMA-253. The Viet Nam war was winding down and funds were being reduced correspondingly. The RF proponents of EW along with the EO supporters declared that flares were done and other technology would take over in a few years. This was in the late 70's. RADM Grady Jackson, now retired, a former head of PME-107, and later in OSD as the EW head, also was not a strong supporter of decoys. He too contended flares were done which is surprising since he was a navy pilot in Viet Nam. It seemed like everyone in the EW business had written off decoy expendables, perhaps motivated by their desire to get a larger share of the funds. Even with these handicaps, we were able to increase our PMA-253 budget for decoys from about 150K in 1970 to 3-4M in 1995.

Reorganizations continued in the exploratory development area as well. In about the mid-1980's, all EW development funds were taken from the Commands and given as a block to NRL by ONR. Non-decoy funds had disappeared earlier. NAD Crane now had to compete for air decoy projects with other claimants for the funds in the EW block. NRL has the lead for all ship decoy projects. The exploratory development budget for air decoys went to zero in FY2003.

In August 1994, Mr. Steve Norris was appointed the NAVAIR technical agent (Lead Commodity Engineer) for Infrared Expendable Countermeasures. At that time the Program Manager Air (PMA) responsible for this commodity was PMA-253, which later became PMA-272. As Mr. Norris took hold, Dr. Douda progressively relinquished his infrared decoy administrative duties to him. Also about 1994, PMA-272 split off the Electronic Warfare (EW) expendables acquisition group to form PMA-222 at the Naval Air Station, Jacksonville FL. In 1996, PMA-222 was absorbed back into PMA-272 in preparation for the relocation by 1 October 1997 of PMA-272 from Crystal City, Arlington VA area to the Naval Air Warfare Center, Aircraft Division, Patuxent River MD.

Written in 2002 by Bernard. E. Douda and edited in January 2008.

Composition Designations

The series designated PL (Pilot Lot)

The “NOTS Standard” infrared composition prior to the introduction of Viton® A was 54% magnesium gran -16, 30% Teflon® #1 600μm particle size, and 16% Kel-F® #10 wax. This was the standard prior to the introduction of the shock-gel process in 1959. The Kel-F wax composition has low tensile strength and exhibited an electrostatic sensitivity at the 50% point of 0.76 joules. The density, after fabrication into a grain, is only about 90% of theoretical.

PL 6010: Igniter composition consisting of 16% magnesium and 84% Teflon® #5 molding powder.

PL 6011: Igniter composition consisting of 66% magnesium and 34% Teflon® #5 molding powder.

PL 6012: Igniter composition consisting of 31.08% magnesium, 63.92% Teflon® #5 molding powder and 5% sodium fluoride.

PL 6013: Igniter composition consisting of 31.08% magnesium, 63.92% Teflon® #5 molding powder and 5% potassium dichromate.

PL 6014: Igniter composition consisting of 16.09% magnesium, 33.08% Teflon® #5 molding powder, 45.83% potassium perchlorate, and 4% potassium dichromate.

PL 6014A: Igniter composition consisting of 18.12% magnesium, 37.25% Teflon® #5 molding powder, 39.63% lithium perchlorate, and 5% potassium dichromate.

PL 6020: Igniter composition consisting of 25.13% aluminum, 69.87% Teflon® #5 molding powder, and 5% sodium fluoride.

PL 6022: Igniter composition consisting of 25.13% aluminum, 69.87% Teflon® #5 molding powder, 2.5% sodium fluoride and 2.5% potassium dichromate.

PL 6023: Igniter composition consisting of 31.08% magnesium, 63.92% Teflon® #5 molding powder, 2.5% sodium fluoride and 2.5% potassium dichromate.

PL 6024: Igniter composition consisting of 11.98% boron, 83.02% Teflon® #5 molding powder, 2.5% sodium fluoride and 2.5% potassium dichromate.

PL 6025: Igniter composition consisting of 23.75% aluminum, 23.75% boron, 47.50% Teflon® #5 molding powder, 2.5% sodium fluoride and 2.5% potassium dichromate.

PL 6026: Igniter composition consisting of 10% aluminum, 50% boron, 35% Teflon® #5 molding powder, 2.5% sodium fluoride and 2.5% potassium dichromate.

PL 6027: Igniter composition consisting of 5% aluminum, 85% boron, 7% Teflon® #5 molding powder, 1.5% sodium fluoride and 1.5% potassium dichromate.

PL 6032: Igniter composition consisting of 5% aluminum, 18.13% boron, 7% Teflon® #5 molding powder, 66.87% lithium perchlorate, 1.5% sodium fluoride and 1.5% potassium dichromate.

PL 6033: Igniter composition consisting of 66.4% thorium, 28.60% Teflon® #5 molding powder, 2.5% sodium fluoride and 2.5% potassium dichromate.

PL 6041: Igniter composition consisting of 9% magnesium, 33.39% zirconium, 44.97% Teflon® #5 molding powder, 9% lithium perchlorate, 3% potassium dichromate, and 9% lead fluoride. The zirconium is 50 to 100 mesh obtained from City Chemical Corporation.

PL 6042: Igniter composition consisting of 9% magnesium, 21.53% titanium, 26.61% Teflon® #5 molding powder, 9% lithium perchlorate, 3% potassium dichromate, and 9% lead fluoride. The titanium is less than 325 mesh obtained from City Chemical Corporation.

PL 6043: Igniter composition consisting of 9% magnesium, 27.31% molybdenum, 42.69% Teflon® #5 molding powder, 9% lithium perchlorate, 3% potassium dichromate, and 9% lead fluoride. The molybdenum is 200 mesh obtained from City Chemical Corporation.

PL 6054: Igniter composition consisting of 45.32 zirconium, 49.68% Teflon® #5 molding powder, 2.5% sodium fluoride, and 2.5% potassium dichromate. The zirconium is less than 200 mesh obtained from Metal Hydrides, Inc.

PL 6077: Igniter composition consisting of 50% magnesium, 25% Teflon® #5 molding powder, 7.5% sodium fluoride, 7.5% potassium dichromate, and 10% Kel® F oil #10. The Kel® F oil #10 was obtained from 3M, formerly Kellogg.

PL 6078: Igniter composition consisting of 40% magnesium, 35% Teflon® #5 molding powder, 7.5% sodium fluoride, 7.5% potassium dichromate, and 10% Kel® F oil #10. The Kel® F oil #10 was obtained from 3M, formerly Kellogg.

PL 6079: Igniter composition consisting of 30% magnesium, 45% Teflon® #5 molding powder, 7.5% sodium fluoride, 7.5% potassium dichromate, and 10% Kel® F oil #10. The Kel® F oil #10 was obtained from 3M, formerly Kellogg.

PL 6080: Igniter composition consisting of 20% magnesium, 55% Teflon® #5 molding powder, 7.5% sodium fluoride, 7.5% potassium dichromate, and 10% Kel® F oil #10. The Kel® F oil #10 was obtained from 3M, formerly Kellogg.

PL 6081: Igniter composition consisting of 25% magnesium, 25% boron, 25% Teflon® #5 molding powder, 7.5% sodium fluoride, 7.5% potassium dichromate, and 10% Kel® F oil #10. The Kel® F oil #10 was obtained from 3M, formerly Kellogg.

PL 6084: Igniter composition consisting of 60% magnesium, 15% Teflon® #5 molding powder, 7.5% sodium fluoride, 7.5% potassium dichromate, and 10% Kel® F oil #10. The Kel® F oil #10 was obtained from 3M, formerly Kellogg.

PL 6085: Igniter composition consisting of 31.08% magnesium, 63.92% Teflon® #5 molding powder, 2.5% sodium fluoride, 2.5% potassium dichromate, and 10% Kel® F oil #10. The Kel® F oil #10 was obtained from 3M, formerly Kellogg.

PL 6239: IR flare and ignition composition consisting of 54% magnesium (45-75µ), 30% Teflon® #7 (35µ), and 16% Viton® A. Another source states PL 6239 is an IR flare composition consisting of 54% magnesium gran 16, 30% Teflon® #5 (reground to 35µ), and 16% Viton® A.

PL 6246: Underwater flare composition: 30.5% magnesium gran 16, 49.7% Teflon® #7, 16.3% Viton® A, 1% aluminum, 1 % boron, and 1.5% sodium chloride.

PL 6278: IR flare composition: 54% magnesium gran16, 22.5% Teflon® #7 (35µ), 7.5% Teflon® #5 (300µ), and 16% Viton® A.

PL 6279: IR flare composition: 54% magnesium gran16, 15% Teflon® #7 (35µ), 15% Teflon® #5 (300µ), and 16% Viton® A.

PL 6280: IR flare composition: 54% magnesium gran16, 7.5% Teflon® #7 (35µ), 22.5% Teflon® #5 (300µ), and 16% Viton® A.

PL 6281: IR flare composition: 54% magnesium gran16, 22.5% Teflon® #7 (35µ), 7.5% Teflon® #1 (600µ), and 16% Viton® A.

PL 6282: IR flare composition: 54% magnesium gran16, 15% Teflon® #7 (35μ), 15% Teflon® #1 (600μ), and 16% Viton® A.

PL 6283: IR flare composition: 54% magnesium gran16, 7.5% Teflon® #7 (35μ), 22.5% Teflon® #1 (600μ), and 16% Viton® A.

PL 6287: IR flare composition: 54% magnesium gran16, 5% Teflon® #7 (35μ), 12.5% Teflon® #5 (300μ), 12.5% Teflon® #1 (600μ), and 16% Viton® A.

PL 6288: IR flare composition: 54% magnesium gran16, 10% Teflon® #7 (35μ), 10% Teflon® #5 (300μ), 10% Teflon® #1 (600μ), and 16% Viton® A.

PL 6289: IR flare composition: 54% magnesium gran16, 15% Teflon® #7 (35μ), 7.5% Teflon® #5 (300μ), 7.5% Teflon® #1 (600μ), and 16% Viton® A.

PL 6290: IR flare composition: 54% magnesium gran16, 20% Teflon® #7 (35μ), 5% Teflon® #5 (300μ), 5% Teflon® #1 (600μ), and 16% Viton® A.

PL 6294: IR flare composition: 64% magnesium gran15 and 36% Viton® A.

PL 6295: IR flare composition: 64% magnesium gran15, 20% Teflon®, and 16% Viton® A.

PL 6296: IR flare composition: 64% magnesium gran16 and 36% Viton® A.

PL 6297: IR flare composition: 64% magnesium gran17 and 36% Viton® A.

PL 6298: IR flare composition: 64% magnesium gran17, 20% Teflon®, and 16% Viton® A.

PL 6299: IR flare composition: 64% magnesium gran16, 20% Teflon®, and 16% Viton® A.

PL 6309: IR flare composition: 54% magnesium gran 15, 30% Teflon® #5 (reground to 35μ), and 16% Viton® A.

PL 6320: IR flare composition: 54% magnesium gran16, 30% Teflon® #7 (35μ), and 16% Viton® A. This is the “improved” formula that came about with the shock-gel process in 1959. It has an electrostatic sensitivity of 12.5 joules (no fires in 10 trials), is easy to extrude at temperatures ranging from 150F to 225F in a conventional double-base propellant extrusion press. Compression molding can also process the composition. The extruded forms can be machined, and have tensile strengths and elongation that withstand application forces.

PL 6328: IR flare composition: 54% magnesium gran16, 30% Teflon® #1 (600μ), and 16% Viton® A. The density is 1.8 grams per cubic centimeter.

PL 6353: IR flare composition: 58% magnesium gran16, 30% Teflon® #5 (300μ), and 12% Viton® A.

PL 6364: IR flare composition: 50% magnesium gran16, 30% Teflon® #5 (reground to 35μ), and 20% Viton® A.

PL 6365: IR flare composition: 50% magnesium gran16, 20% Teflon® #5 (reground to 35μ), and 30% Viton® A.

PL 6366: IR flare composition: 50% magnesium gran16, 10% Teflon® #5 (reground to 35μ), and 40% Viton® A.

PL 6367: IR flare composition: 60% magnesium gran16, 30% Teflon® #5 (reground to 35μ), and 10% Viton® A.

PL 6368: IR flare composition: 60% magnesium gran16, 20% Teflon® #5 (reground to 35μ), and 20% Viton® A.

PL 6369: IR flare composition: 60% magnesium gran16, 10% Teflon® #5 (reground to 35μ), and 30% Viton® A.

PL 6370: IR flare composition: 70% magnesium gran16, 20% Teflon® #5 (reground to 35μ) and 10% Viton® A.

PL 6371: IR flare composition: 70% magnesium gran16, 10% Teflon® #5 (reground to 35μ), and 20% Viton® A.

PL 6373: IR flare composition: 54% magnesium (325 mesh), 30% Teflon® #5 (Reground to 35μ), and 16% Viton® A.

PL 6377: IR flare composition: 58% magnesium gran16, 30% Teflon® #7 (35μ), and 12% Viton® A.

PL 6378: IR flare composition: 54% magnesium gran16, 7.5% Teflon® #5 (300μ), 22.5% Teflon® #7 (35μ), and 16% Viton® A.

PL 6379: IR flare composition: 54% magnesium gran16, 15% Teflon® #5 (300μ), 15% Teflon® #7 (35μ), and 16% Viton® A.

PL 6380: IR flare composition: 54% magnesium gran16, 22.5% Teflon® #5 (300μ), 7.5% Teflon® #7 (35μ), and 16% Viton® A.

PL 6381: IR flare composition: 54% magnesium gran16, 7.5% Teflon® #1 (600μ), 22.5% Teflon® #7 (35μ), and 16% Viton® A.

PL 6382: IR flare composition: 54% magnesium gran16, 15% Teflon® # 1, 15% Teflon® #7, and 16% Viton® A.

PL 6383: IR flare composition: 54% magnesium gran16, 22.5% Teflon® # 1, 7.5% Teflon® #7, and 16% Viton® A.

PL 6384: IR flare composition: 54% magnesium gran16, 22.5% Teflon® #5 (300μ), 7.5% Teflon® #1 (600μ) and 16% Viton® A.

PL 6385: IR flare composition: 54% magnesium gran16, 15% Teflon® #5 (300μ), 15% Teflon® #1 (600μ) and 16% Viton® A.

PL 6386: IR flare composition: 54% magnesium gran16, 7.5% Teflon® #5 (300μ), 22.5% Teflon® #1 (600μ) and 16% Viton® A.

PL 6387: IR flare composition: 54% magnesium gran16, 12.5% Teflon® #5 (300μ), 12.5% Teflon® #1 (600μ), 5% Teflon® #7 (35μ) and 16% Viton® A.

PL 6388: IR flare composition: 54% magnesium gran16, 10% Teflon® #5 (300μ), 10% Teflon® #1 (600μ), 10% Teflon® #7 (35μ) and 16% Viton® A.

PL 6389: IR flare composition: 54% magnesium gran16, 7.5% Teflon® #5 (300μ), 7.5% Teflon® #1 (600μ), 15% Teflon® #7 (35μ) and 16% Viton® A.

PL 6390: IR flare composition: 54% magnesium gran16, 5% Teflon® #5 (300μ), 5% Teflon® #1 (600μ), 20% Teflon® #7 (35μ) and 16% Viton® A.

PL 6392: IR flare composition: 54% magnesium gran16, 15% Teflon® #5 (reground to 35μ), 15% Teflon® #5 (300μ), and 16% Viton® A.

PL 6393: A visual flare formula. 47% magnesium (200-300 mesh), 28% sodium nitrate, 15% Teflon® (600μ), and 10% Viton® A: Extruded.

PL 6396: IR flare composition: 54% magnesium gran16, 15% Teflon® #5 (reground to 35μ), 15% Teflon® #1 (600μ), and 16% Viton® A.

PL 6397: IR flare composition: 54% magnesium gran16, 16% Viton® A, and 30% Kynar®. The latter is polyvinylidene fluoride.

PL 6500: A visual flare formula. 47% magnesium (200-300 mesh), 28% sodium nitrate, 15% Teflon® (300μ), and 10% Viton® A: Extruded.

PL 6501: A visual flare formula. 39% magnesium (200-325 mesh), 25% sodium nitrate, 32% Teflon® (600μ), and 4% Viton® A: Extruded.

PL 6502: A flare formula consisting of 35% magnesium (200-325 mesh), 22.5% sodium nitrate, 29% Teflon®-1 (600μ), 3.5% Viton® A and 10% polystyrene beads. It is claimed that the addition of the beads converts the radiation from visible to the IR. This composition can be extruded.

PL 6503: A high altitude ignition composition that sustains ignition at 150,000 feet altitude (1.1 torr). It consists of 54% magnesium (3-5μ), 30% Teflon® #1 (600μ), and 16% Viton® A.

PL 6809: Illumination formula consisting of 56% magnesium (30/50 granular particle size), 35% sodium nitrate, and 4% Viton® A.

PL 6842: Illumination formula consisting of 56% magnesium (gran 17), 37% sodium nitrate, and 7% Viton® A.

PL 6920: IR flare formula consisting of 70% magnesium gran 16, 14% Teflon® #7, and 16% Viton® A, It is a very high output-short burning composition. A second formula was reported as 70% magnesium gran 16, 15% Teflon® #7, and 15% Viton® A as a composition capable of being extruded.

PL 6920-1: IR flare formula consisting of 2.5% graphite added to a PL 6920 composition. Not good for extruding.

PL 6920-2: IR flare formula consisting of 5% graphite added to a PL 6920 composition. Not good for extruding.

PL 6920-3: IR flare formula consisting of 10% graphite added to a PL 6920 composition. This composition extrudes well.

PL 6920G: IR flare formula consisting of 18% to 20% graphite added to a PL 6920 composition. Graphite is added to assist extrusion and regulate burning. This composition extrudes well. The grains burned faster than the 3 seconds desired. Ignition at 40,000 feet altitude is satisfactory.

PL 7078: Similar to PL 6920G but contains 63% magnesium.

PL 8005: IR flare formula consists of 54% magnesium, 30% Teflon®, 4% Viton® A, and 12% Krayton 101 binder. The latter is a polybutadiene-styrene copolymer.

PL 9000: Early variant: The IR formula consists of 63% magnesium, 13.5% Teflon®, 13.5% Viton® and 10% graphite. Dry blending the graphite with the PL 6920 extrusion powder makes this formula. Used in Ex 49 Mod 0 and Mk 49 Mod 0 decoy flare grain.

PL 9000: Later variant: The IR formula consists of 63% magnesium, 13.5% Teflon®, 13.5% Viton® and 10% graphite. This formula is made with the graphite being added to the PL 6920 extrusion powder slurry before shock precipitation of the binder.

PL 9001: In August 1973, the Naval Air Systems Command (NASC) issued a material specification for an IR flare composition consisting of 54% atomized magnesium, 30% Teflon® and 16% Viton® A. The heat of explosion for this mixture is about 1450 calories per gram. The specification covers a precipitated powder mixture called Type I and a mixture used to make extruded grains called Type II. Type I flare mixture is used in ignition trains. The Type II mixture is used as the main charge in igniters and flares. Composition PL 9001 is similar to N-35 Propellant in formulation but allows a wider magnesium particle size range.

CT-070 Flare Mix: This is an infrared flare mix. It is made up of composition PL 6920, a very high output-short burning composition.

Formula 256 for Cast Flare: This is a formula to make a cast grain from 46% magnesium, 28.9% ammonium perchlorate, 1.4% Viton® and 23.5% Sylgard® 182.

FW-306 Flare Composition: This is an infrared composition used in the ALA-17 flare consisting, in parts by weight, of 54 parts magnesium, 46 parts Teflon®, and 2.6 parts nitrocellulose.

SI-119 Infrared Flare Composition: This is a composition developed at Picatinny Arsenal that radiates in the 1.8μm to 2.8μm bandpass region. It is reported to be unaffected by increasing altitude up to 60,000 feet, when it tapers off slightly. The constituents are molybdenum trioxide, chromic oxide, and zirconium.

Other Designations

A-1A Gasless Ignition Powder: This powder is under cognizance of the Naval Air Systems Command. It consists of 65% zirconium powder, 25% ferric oxide, and 10% diatomaceous earth.

CT-0025 Ignition Composition: This is an ignition composition consisting of 9.8% boron, 88.2% barium chromate and 2.0% zinc stearate. It exhibits an electrostatic sensitivity of 0.596 joules, a 10-fold decrease in electrostatic sensitivity as compared to the FD-30 ignition composition.

CT-144 Igniter Mix: This is an igniter mix used to make the pellet that ignites the grain in the EX 49 Mod 0 decoy flare. It also is used as an igniter mixture, which is painted on both ends of the N-35 propellant used in the Mk 50 Mod 0 decoy flare. This igniter mix also was planned for use to ignite composition PL 9000 in the EX 51 Mod 0 flare.

D-16 Delay Powder: D-16 is a gasless manganese-type delay composition developed at NOL White Oak about the mid 1950s. It consists of manganese, barium chromate and lead chromate and is described in specification Mil-M-21383. Variants of the formula allow tailoring of the burning rate through the range of 3.7 to 13.5 seconds per inch.

F-33B Gasless Ignition Powder: F-33B powder is under the cognizance of Picatinny Arsenal. This mixture consists of 41% zirconium powder, 49% ferric oxide, and 10% diatomaceous earth.

FA878 Igniter Mix: (FA=Frankfort Arsenal) This igniter mix consists of 32.5% zirconium (one-grade), 7.5% zirconium (another grade), 20% barium nitrate, 20% lead dioxide, and 20% pentaerythritol tetranitrate (PETN).

FD-30 Igniter Composition: This composition consists of 10% boron and 90% barium chromate. It exhibits an electrostatic sensitivity of 0.0528 joules.

FW-210 Ignition Mix: This mixture consists of manganese dioxide and zirconium. The mix is effective at high and low altitudes.

H-9 Propellant: The 1948 version of the FFAR rocket contains the H-9 propellant.

K Composition: This is an improved igniter "K" composition containing dichromated 50/50 Mg/Al alloy or 65/35 Mg/Al alloy instead of unalloyed magnesium. Dr. Hart, Picatinny Arsenal, developed this composition about 1944.

N-4 Propellant: The N-4 propellant replaced the H-9 propellant in the FFAR rocket in the fall of 1950. The N-4 Propellant introduced a low temperature ignition problem with the Mk 125 Mod 0 igniter then in use.

N-35 Propellant: The N-35 propellant consists of magnesium-Teflon®-Viton® and is similar to composition PL 9100 in formulation but requires a narrower magnesium particle size range. It is 1.4 inches in diameter by 2.4 inches long and is used in the Mk 50 Mod 0 decoy flare in 1972. It is relatively insensitive. It has an 8-point internal star, the points of which are shaved off for greater surface. Ignition mix CT-144 is painted on both ends.

Rapec Mix Ignition Composition: This is a first fire mixture that consists of zirconium, lead dioxide and polymethylvinyltetrazole (PMTV) the latter being dissolved in methylene chloride. It is used as a flare grain coating. The Rapec mix is electrostatic and friction sensitive. It is used in the EX 46 Mod 0 decoy flare and its predecessor the NOTS Model 400A decoy flare. Reportedly, it is superior to FD-30 ignition composition.

Z-2 Heat Paper: This is an inorganic paper that is impregnated with zirconium-barium chromate.

Squibs and Thermites

NOTS Model 4 Squib: The NOTS Model 4 squib might have been the forerunner to the Mk 1 Mod 0 squib.

NOTS Model 39 Pyrogen Squib: The development of this squib resulted from a need for a reliable technique for electric ignition of flares at high altitude, up to 190,000 feet. This is a self-contained ignition device with a grain and nozzle inside of a hermetically sealed case that is capable of igniting flares without aid from additional materials. It is fabricated in the same external configuration as the Mk 1 Mod 0 squib. The NOTS Model 39 pyrogen squib reliably ignites 1-inch diameter test flares at simulated altitudes to 190,000 feet (0.25 torr). Investigators considered the use of a bridge wire with the Mk 2 squib. The latter has characteristics to reduce electromagnetic radiation hazards. (HERO).

NOTS Model 39A Pyrogen Squib: This squib is installed in the NOTS Model 726B flare to get better high altitude ignition.

Mk 1 Mod 0 Squib: This squib is installed in 2.75-inch rockets. It also is used to ignite the NOTS Model 702 flare series.

Mk 2 Squib: In 1964, Picatinny Arsenal improved this squib to make it HERO safe. This also is implied in remarks regarding the development of the NOTS Model 39 pyrogen squib. The squib is rated 5-amp.

Mk 3 Squib: No data located.

M35 Squib: McCormick Selph made this squib. Universal Match Corporation used it during flare composition evaluations.

M37 Squib: Universal Match Corporation used this squib during flare composition evaluations.

F-ND Model 706 Squib aka USF Model 706 Squib: This squib manufactured by Flare Northern Division of the Atlantic Research Corporation or U. S. Flare Division of the Atlantic Research Corporation is used in the W137 tracking flare, the W211 flare, and the W211 target flare.

Mk 131 Mod 0 Impulse Cartridge: This cartridge is used to eject the Mk 49 Mod 0 flare from its dispenser. Impulse cartridges are sometimes called squibs.

Model 194 Pot: This is a thermite filled carbon crucible that weighs 16 pounds. Six of these pots are installed on the F6F-5K drone. Starting in 1958, the F6F-5K drone was replaced by the Ryan KDA-1 Firebee drone powered by one Continental J69 turbo-jet engine. The Firebee drone is augmented with two clusters of the NOTS Model 702A flares on each wing tip, the Model 194 pot being too heavy.

Identification of Some Additional Flare Related Devices

AN/ALE-11 Dispenser: This dispenser has a pneumatic ejection system with two rows of infrared flares or chaff. The dispenser is 10 inches wide by 6 inches high by 4 feet long. The Flare Northern rectilinear castable flare is designed for use with this dispenser.

AN/ALE-14 Countermeasure Flare Ejector: The ALA-17 flare is dispensed from the AN/ALE-14 countermeasure flare ejector mounted in the B-47 bomber and the B-52 bomber. The RITA-II flare fits this dispenser.

AN/ALE-18 Pneumatic Dispenser: The Mk 43 Mod 0 flare fits this dispenser, as does the NOTS Model 715 flare.

AN/ALE-20 Ejector Set: Originally, this dispenser set was developed for the B-52 aircraft. This assembly contains eight launch tubes with two stacked flares in each tube. The QRC-127 flare is compatible with this dispenser as is the RITA-II flare.

AN/ALE-25 Dispenser: This is a pod mounted dispenser, 154 inches long by 20 inches in diameter accommodating twenty ADR-9A countermeasure rocket systems. The pod is mounted between the engines of the B-52 late model series bomber and weighs 295 pounds unloaded.

AN/ALE-28 Ejector Set: Originally, this dispenser set was developed for the F-111 aircraft. It dispenses the RR-119 decoy flare. It can carry 13 of the 2-inch thick flares in each of two channels.

AN/ALE-29A Chaff Flare Dispenser: This dispenser has 30 cylindrical chambers into which the chaff and flare cartridges are loaded.

AN/ALE-29/39 Chaff Flare dispenser: Goodyear Corporation developed this dispenser set for use on Navy aircraft such as the F-4 and F-8.

AN/ALE-33 Chaff Flare Dispenser: Lundy developed this dispenser. It was used to dispense the MK 42 Mod 0 flare and the NOTS Model 733 flare.

AN/ALE-37 Chaff Flare Dispenser: This dispenser has 240 cylindrical chambers into which the chaff and flare cartridges are loaded.

AN/ALE-39 Chaff Flare Dispenser: This dispenser has 60 cylindrical chambers into which the chaff and flare cartridges are loaded.

AN/ALE-40 Chaff Flare Dispenser: This dispenser, made by Tracor, accepts three different rectilinear flares in the configuration of 1 inch by 1 inch by 8 inches, 1 inch by 2 inches by 8 inches, and 2 inches by 2.5 inches by 8 inches.

LA-307A Photoflash Cartridge Dispenser: The manufacturer of this dispenser is Lambert Engineering, Inc., Saint Louis, Missouri. This cartridge ejector is used with the M-112 photoflash cartridges and the QRC-353 (T)-1 Type I Flare.

LA-308A Photoflash Cartridge Dispenser: The manufacturer of this dispenser is Lambert Engineering, Inc., Saint Louis, Missouri. This cartridge ejector is used with the M-123 photoflash cartridges, the QRC-353 (T)-1 Type II Flare and the MJU-2/B decoy flare. It is internally mounted in the aft end of RF-4 aircraft and has been installed on other aircraft.

M-130 Flare Dispenser: This is an Army dispenser which is capable of firing flares with a 1 inch by 1 inch by 8 inch format. The M-130 dispenser can dispense either 30 decoy flares or 30 chaff cartridges.

Model 30-0011-2 Chaff Dispenser: This dispenser made by Lundy is electrically operated. The RR-72 chaff and the NOTS Model 733A target flare are compatible with this dispenser.

USAF 669A Phase I dispenser: This is an Air Force dispenser, built by Tracor, which is compatible with rectangular configured infrared flares such as the RR-115 flare, the RR-119 flare or the UM-111 flare. The flare format is 2-inch by 2 inch by 5-inch.

XM-126 Dispenser: The XM-126 nomenclature is believed to be that assigned to the dispenser that had been developed for the Army XM-196 mini-flare by ECOM at Fort Monmouth.

NOTS Model 104-G Rocket Flare Head: This is a flare head for a 5.0-inch HVAR motor. It was developed by NOTS in 1952 and contains illuminating composition. It also contains a pyrotechnic delay instead of a mechanical delay. It is the forerunner of the Mk 26 Mod 0 rocket flare head.

NOTS Model 108A Rocket Flare Head: NOTS Inyokern developed this rocket flare head about 1951.

NOTS Model 113A Rocket Flash Head: NOTS Inyokern in 1952 developed the NOTS Model 113A 5-inch flash head for the HVAR rocket. It provides a brilliant flash about 0.067 seconds duration at a given time after the rocket leaves the launcher, thereby marking one point on the rocket's trajectory. The 5-inch flash head is an outgrowth of the 2.75-inch FFAR flash head. It consists of a plaster loaded MK 6 Mod 1 five-inch head, the fuze unit of the 2.75-inch flash head, and a canister tube of flash powder.

Mk 26 Mod 0 Rocket Flare Head: This head is for 5.0-inch FFAR Zuni rocket, the 5.0-inch HVAR, and 5.0-inch high performance air to ground (HPAG) rocket. It contains illumination composition. It is the forerunner of the Mk 33 Mod 0 rocket flare head.

Mk 33 Mod 0 Rocket Flare Head: This head, also containing illumination composition, is an improvement of the Mk 26 Mod 0 rocket flare head. It was designed and developed at NOTS prior to 1964. The flare is ejected from the rocket head. The flare produces 1,000,000 candela for 90 seconds. The flare ejection from the rocket head is base first with a maximum descent rate of 15 feet per second. The goal is 95% reliability and proper function at minus 65 and +165 F. NOL White Oak developed a 14 second delay fuse for the rocket flare head. The delay fuse was first designated as XW-128B flare fuse and later as the Mk 193 Mod 0 flare fuze. Until the NOL fuze became available in 1960, the NOTS Model 553A flare igniter was used for head separation and flare ignition.

NOTS Model 553A Flare Igniter: This igniter is installed in the Mk 33 Mod 0 rocket flare head for head separation and flare ignition.

NOTS Model D634 Igniter: This is the improved modified igniter used in the FFAR rocket after Mr. Eckert of NOTS changed the charge to fix a low-temperature ignition problem with the M125 Mod 0 igniter. The charge is 8-grams of black powder and 2 grams of vinyl-coated magnesium powder. The NOTS Model D634 igniter had ignition failures below minus 40F. By May 1951, a redesigned igniter was developed called the NOTS Model D639 igniter later to be designated the Mk 125 Mod 2 igniter.

NOTS Model D639 Igniter: NOTS Model D634 igniter had ignition failures below minus 40F. By May 1951, a redesigned igniter was developed called the NOTS Model D639 igniter later to be designated the Mk 125 Mod 2 igniter. The NOTS Model D639 igniter is installed in the FFAR rocket. The charge is 8-grams of black powder and 2 grams of vinyl-coated magnesium powder.

Mk 125 Mod 0 Igniter: This igniter in the FFAR rocket contains the N-4 propellant, which introduced a low-temperature problem in the igniter. An improved modified igniter is designated the NOTS Model D634 igniter.

Mk 125 Mod 2 Igniter: This igniter in the FFAR rocket is the improved design by Mr. Eckert of NOTS, which is the successor to the NOTS Model D639 igniter. The Mk 125 Mod 2 igniter contains a charge consisting of is 8-grams of black powder and 2 grams of vinyl-coated magnesium powder.

Mk 2 Mod 0 Ignition Element: This ignition element is used in the bore-safe Navy mini-flare.

M39A1 percussion primer: The Mk 50 Mod 0 flare uses this primer.

Mk 154 Mod 0 Stab Primer: This is the tentative designation for the NOTS Model 668A stab primer.

NOTS Model 668A Stab-initiated Primer: This primer is installed in the NOTS Model 733A target flare. The NOTS Model 668A primer was tentatively designated the Mk 154 Mod 0 stab primer. This primer was released to the NOTS Engineering Department in September 1962.

NOTS Model 751A Flash Signal: This is the flash signal that indicates fuze actuation for the Sparrow I missile.

Mk 1 Mod 0 Flash Signal: This is a Flash Signal for the Sidewinder exercise head.

Mk 2 Mod 0 Flash Signal: This is a Flash Signal for the Sidewinder exercise head.

Mk 36 Mod 0 Signal, Flash, Guided Missile: This is a flash signal for the Sparrow II missile to indicate fuze actuation.

Mk 37 Mod 0 Signal, Flash, Guided Missile: This is a flash signal for the Sparrow III missile to indicate fuze actuation. Researchers in the Pyrotechnics and Fuze Branches at NOTS developed and tested it about 1957.

Mk 193 Mod 0 Flare Fuze: This is a 14-second fuze developed by NOL White Oak, which is installed in the Mk 33 Mod 0 rocket flare head. It earlier was designated the XW-128B flare fuze.

XW-128B Flare Fuse: This fuse designation evolved into the Mk 193 Mod 0 flare fuze.

RR-72 Chaff Cartridge: This chaff cartridge was designed for use in the Lundy Model RC17-101 mechanically operated miniature chaff dispenser and the electrically operated Lundy Model 30-0011-2 chaff dispenser.

Potpourri

Prognosis in 1968 of Decoy Flare Demise:

Mr. B. Richard Case of General Dynamics Corporation, Fort Worth, Texas, during his presentation at the annual IRIS IRCM meeting on “Modern Flare Measurement and Data Reduction Methods” made the following statement about the demise of flares. He first says, “If anyone ever had the opportunity to witness the ground testing of a modern flare, I’m sure you can share my reluctance to refer to these devices as “passive” countermeasures. However, since some distinction had to be made between pulsed infrared jammers and flares, the flares were so classified.” He goes on to say, “There are those who sounded the death knell for passive IRCM. They say that flares are fast becoming obsolete and that the “active” IRCM will soon provide the needed protection. The facts, however, do not support this conclusion. We have seen evidence during this symposium that pulsed jammers are still in the embryonic stage and struggling for survival. Flares, on the other hand, are just maturing.” He concludes by saying, “The point that should be made is that we stand on the threshold of an era in which flares will play a commanding role. Conservative estimates place flares as the primary defense for the next 5-7 years and as a sound secondary defense for another decade afterwards”.

Square vs. Round Holes and the AN/ALE-40 Chaff/Flare Dispenser

About 1969-71, the Air Force had no chaff capability in their fighter size aircraft except the RF-4C fighter, which carried some chaff in their Lambert LAU-308A photoflash flare dispensers. Most Air Force aircraft going to North Viet Nam during that time period dispensed chaff bundles, which had been packed in their speed breaks. This gave them a one-shot protection capability. With knowledge of this limited capability Tracor, Inc., headquartered in Austin Texas, submitted an unsolicited proposal, which lead to a contract award for the development of an advanced pyrotechnic dispensing program. This exploratory development program covers a period from 17 Nov 1969 through completion 15 July 1970. The work was performed as an Air Force Avionics Laboratory Project under the direction of Captain Richard D. Hunziker of the Electronic Warfare Division. Mr. Bennie A. Shupe managed the program at Tracor. The Tracor project engineer was Mr. Robert C. James. Tracor’s engineers accomplishing the work were Mr. Rod Johnson, Mr. Willie Laubach and Mr. Sidney Lanier. As a vehicle to test their experimental square and hexagonal chaff units, Tracor investigators built experimental dispenser modules with square and hexagonal holes. They wanted to compare chaff performance from these dispenser modules with square holes to performance of chaff launched from the AN/ALE-29A dispenser and the Lambert LA-308A dispenser, both of which have cylindrical holes. The cartridge for the AN/ALE-29A is 1.43 inches in diameter by 5.81 inches long. The cartridge for the Lambert LA-308A dispenser is 1.568 inches in diameter by 7.625 inches long.

Experimental square and hexagonal cartridges were fabricated and functioned in the laboratory. These experimental cartridges contained the same amount (weight and volume) of chaff as the cylindrical RR-136B chaff cartridge, which is compatible with the Lambert LA-308A dispenser. In addition, special dispenser modules were fabricated to enable testing of each of the experimental square and hexagonal cartridges. Performance of the experimental cartridges launched from the dispenser modules was compared to performance of the RR-136B chaff cartridge launched from the Lambert LA-308A dispenser.

Photographic data from laboratory tests conducted by Tracor indicated a definite improvement in early chaff cloud blooming characteristics when cartridges with a square or rectilinear cross-section are used. An early chaff bloom is very desirable and would result in a major electronic warfare improvement. The Tracor team stated it could result in an increase in radar cross-section due solely to the square configuration of the chaff payload. The Tracor team reported further that a more area, volume and weight efficient system could be designed by using cartridge shapes other that cylindrical. They assigned greater packaging efficiency of square vs. round as the second reason for using square cartridges for chaff, the first being early chaff blooming.

The square cartridges launched from the experimental dispenser module during ground tests showed an average efficiency improvement in chaff blooming of 32% over the RR-136B chaff cartridge launched from the Lambert LA-308A dispenser with cylindrical holes. The square cartridges in the experimental dispenser showed average efficiency improvement in chaff blooming of 13% on a weight-volume basis as compared to the same quantity of chaff launched from an AN/ALE-29A dispenser with cylindrical holes. Based on these favorable results, it was decided to follow with a flight test in November 1971.

Of the four experimental units prepared for flight test, the standard square cartridge payload performed the best. It contained the same dipole band cuts as for the RR-136B/ALE payload, with the same theoretical radar cross-section and specification. During flight tests, the standard square cartridge payload performance was slightly superior in performance with respect to the standard RR-136B/ALE payload. This slight increase is accounted for by the square geometry of the cross-section contrasted to the circular cross section of the RR-136B/ALE, presenting corners of each band cut to airstream impact pressures for early onset of the payload ablation process, enhancing performance of all band cuts of the square cartridge configuration. The large average efficiency improvement in early chaff blooming that was observed during the ground-testing phase was not realized during the flight test phase. Nevertheless, it was concluded that a lighter and more compact pyrotechnic chaff and flare dispenser could be built which would be capable of launching chaff with a square or rectilinear cross-section. The proven benefit of this square configuration derives from the close packing of square units as compared to packing of round units. The close-packing advantage in itself is considered to be a substantial benefit. Based on the ground test and flight test data, a decision was

made to develop a dispenser with rectilinear holes and chaff cartridges in a configuration to fit the new dispenser design. The referenced experimental dispenser module in this work is the forerunner of the AN/ALE-40 chaff/flare dispenser design with rectilinear cross-section holes.

Next, the results of the exploratory development program were transferred to the Aeronautical Systems Division of WPAFB. There Mr. Eubert McDaniel and Mr. Jim Meyer of ASD started the engineering development of the AN/ALE40 in the 1970s by way of a contract with Tracor.

Technical Directors: Rewards for superior achievement.

During the process of discovery of data for this collection, it was noted that some individuals that had been involved in superior technological advances soon were elevated to senior positions. Perhaps this is a reward for their outstanding accomplishments. Some of the more prominent examples are:

(1) By 1951, Mr. L. T. E. Thompson was the Technical Director of NOTS. Mr. Thompson and Cdr. Chick Howard, USN first formulated the Principles of Operation at China Lake. The principles were meant to make clear that civilian scientists worked in partnership with the military at China Lake, not in subordination to it.

(2) By September 1955, Dr. William B. McLean had become the Technical Director at NOTS. Dr. McLean is the father of the Sidewinder missile.

(3) By 1960, Dr. William S. McEwan had become the Technical Director at NOTS. Dr. McEwan reported on a system for the computation of gaseous products of combustion to determine their equilibrium composition and thermodynamic properties of the combustion gases. In 1951, Dr. McEwan and Dr. Sol Skolnik developed an analog computer that electrically simulates the conditions of temperature, pressure and composition of rocket and missile combustion products.

(4) During 1982-86, Dr. Burrell Hays was Technical Director at the Naval Weapons Center, China Lake. Dr. Hays was closely associated with the re-installment of the Principles of Operation, which Rear Adm. Roland Freeman III had done away with in 1974.

(5) By 1958 Dr. Skolnik had become the Director of the Research and Development Department at the U. S. Naval Powder Factory (NPF), Indian Head Maryland. In 1951, Dr. McEwan and Dr. Sol Skolnik developed an analog computer that electrically simulates the conditions of temperature, pressure and composition of rocket and missile combustion products.

Dates Important to the Author

The author came to the Navy during the Korean War, just out of college. He spent several years first as a military person and later as a civilian at NAD Crane developing Army, Air Force and Navy devices containing illuminating compositions. These were urgently needed in Korea. This experience later was the basis for a PhD thesis in 1973 involving illuminating compositions containing sodium nitrate. By this time Vietnam was in full swing and the Services were in dire need of protection from heat-seeking missiles. Research and development of infrared decoy flares was a natural follow-on to illumination, that being merely a change in wavelength from developing energetic materials in the visible to development of flares in the infrared. Next are some dates in which the author had some special interest.

1923: The magnesium-sodium nitrate-binder illuminating composition was invented in the Development Department, Woolwich Arsenal, UK
June 1950 - 27 July 1953: Korean War years
27 July 1953: Korean War cease-fire signed
2 August 1964: Golf of Tonkin
1965 - 1975: Vietnam War years
April 1972: Fall of Saigon

TM 9-1370-201-12

DEPARTMENT OF THE ARMY TECHNICAL MANUAL

OPERATOR'S AND ORGANIZATIONAL MAINTENANCE MANUAL

FLARE, AIRCRAFT: PARACHUTE, MK45

HEADQUARTERS, DEPARTMENT OF THE ARMY

JULY 1969

TECHNICAL MANUAL
No. 9-1370-201-12

HEADQUARTERS
DEPARTMENT OF THE ARMY
WASHINGTON, D. C., *8 July 1969*

OPERATOR'S AND ORGANIZATIONAL MAINTENANCE MANUAL

FLARE, AIRCRAFT: PARACHUTE, Mk45

LIST OF ILLUSTRATIONS

CHAPTER 1

INTRODUCTION

1-1. Scope

These instructions provide operator and organizational maintenance for Flare Mk45. This flare provides lighting for battlefield illumination, target marking and reconnaissance. They are launched internally from fixed-wing and rotary-wing aircraft.

1-2. Forms, Records and Report

a. General. Commanding Officers of units receiving this ammunition are responsible for preparation of records and reports. For reporting purposes, ammunition is identified by lot numbers, standard nomenclature, etc.

b. Field Reports of Accidents. Accidents involving injury to personnel or damage to material are reported on DA Form 285 or DA Form 1051, in accordance with instructions in AR 385-40.

c. Malfunction Reports.

(1) *Definition of a malfunction.* A malfunction is a failure of the flare to perform as expected when armed or launched. For reporting purposes, malfunctions do not include accidents and fires resulting from negligence, malpractice and the like. However, malfunctions do include abnormal or premature functionings which occur during normal handling, maintenance, storage, transportation and tactical deployment.

(2) *Malfunctions involving standard issue items.* The procedure in AR 700-1300-8 will be followed in reporting malfunctions which occur during the following:

(*a*) Training and combat missions.

(*b*) Tests (including comparison, safety, climatic, reliability, etc.) conducted subsequent to the acceptance test.

d. Report of Damaged or Improper Shipment. Damaged or improper shipments will be reported immediately to the forward supply unit (FSU), ammunition supply point (ASP) or depot from which the flares were issued.

e. Fire Reports. As prescribed by AR 385-12, DA Form 5-2 will be used to report fires or explosions followed by fire. DA Form 5-2 will be submitted in addition to the accident reports required by AR 385-40.

f. Errors, Omissions and Recommended Changes. The reporting of errors, omissions and recommendations for improving this publication is authorized and encouraged. In this connection, DA Form 2028 will be used. Completed forms will be forwarded direct to the Commanding Officer, Picatinny Arsenal, ATTN: SMUPA-DC5, Dover, N. J., 07801.

CHAPTER 2

SAFETY, CARE AND HANDLING

2-1. Precautions

a. Handle flares with utmost care at all times.

b. Do not drop, drag, throw, tumble or otherwise strike boxes containing flares.

c. Exercise care if flares show evidence of moisture inside the flare container. Dispose of Flares Mk45 that have been exposed to moisture.

d. Avoid exposing flares to extreme (high or low) temperatures.

e. Do not remove damaged fuzes from flares. Consider flares with damaged fuzes hazardous. Contact authorized munitions personnel immediately for disposal.

f. Do not touch, move or otherwise handle duds -- their fuses may be armed. Have authorized personnel only destroy duds.

2-2. Safety

WARNING

Unauthorized alteration of flares is prohibited. Except as otherwise indicated in this manual, Aircraft Parachute Flare Mk45 is safe to handle and use.

2-3. Care

Flares are packed to withstand conditions ordinarily encountered in the field. Although the polystyrene containers provide adequate protection for shipment and storage, observe the following:

a. Keep polystyrene containers from becoming broken or damaged.

b. Repair or replace broken containers immediately and re-mark those bearing illegible markings.

c. Protect flares against such foreign matter as mud, sand, moisture, frost, snow, ice, dirt, oil and grease. Wipe off wet or dirty flares at once and remove any light corrosion.

d. Do not open containers until flares are to be used.

NOTE

Flares removed from containers, particularly in damp climates, may corrode, becoming unserviceable

2-4. Handling

a. Have flares handled by trained, experienced personnel only. Do not subject flares to rough treatment.

b. Protect flares from hard knocks or blows.

CAUTION

The flare outer container is easily dented, which may result in nonejection or faulty ejection of the candle.

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CHAPTER 3

OPERATING INSTRUCTIONS

3-1. General

This chapter describes the physical characteristics, functioning and operation of Aircraft Parachute Flare Mk45 (fig. 3-1). Flare Mk45 is a pyrotechnic device which provides illumination in the two-million candlepower range for a period of approximately 3 1/2 minutes. It is designed for launch (using a static line technique) from fixed-wing and rotary-wing aircraft.

3-2. Description

The major components of Flare Mk45 are described below and illustrated in figures 3-1 and 3-2.

a. An *outer container*, consisting of an aluminum tube, magnaformed to a fuze adapter, houses the flare and fuze assembly. The container is approximately 2 1/4 inches shorter than the assembled flare, and part of the plastic fuze assembly extends beyond the end of the outer container. A decal on the container body gives fuze setting and safing information.

b. A plastic *shipping cap* covers the fuze end of the assembled flare and protects the fuze area during shipment and storage.

c. A *lanyard assembly* is coiled under the shipping cap. It consists of a stainless steel cable with a double coil loop at one end for attachment to an attachment loop and toggle in the fuze assembly. A swivel snaphook is attached to a loop in the lanyard about 4 1/2 inches from the coil.

d. A black plastic *lanyard retainer* is attached to the lanyard adjacent to the swivel snaphook. (The lanyard retainer is not used in hand launch procedures.)

e. A two-pronged *safety clip* holds the toggle in place in an aluminum housing in the center of the fuze mechanism. A yellow tag, attached to the prongs of the safety clip by a split key ring, warns the user not to remove the safety clip.

f. An *ejection fuze assembly*, which controls candle and parachute ejection, is secured to the flare by a fuze adapter.

(1) The fuze proper consists of an internal disconnect, a striker and plunger assembly, a 2 second (nominal) fixed delay element, a time delay fuse, and an expelling charge.

(2) The fuze setting mechanism consists of a single yellow dial indicator which can be set at 15 different positions, ranging from 500 to 14,000 feet. The setting points are marked in black on the face of the fuze. Raised projections at SAFE and at each setting point facilitate setting the fuze in total darkness. A spring-loaded detent holds the dial indicator at the selected setting.

g. A *gas check* and a *compression pad* are positioned between the fuze assembly and the candle assembly.

h. The 18-pound *candle assembly* is, essentially a paper tube containing a magnesium candle. A detonator, an explosive bolt and a suspension cable (see (9), below) are attached to one end of the assembly.

i. A *suspension/ignition assembly* which provides ignition for the candle connects the parachute and candle assemblies. A firing pin, a primer and an ignition pellet constitute the ignition assembly. The suspension assembly consists of a cable attached at one end to the explosive bolt in the candle assembly and at the opposite end, to the parachute.

j. The *parachute assembly* consists of a main parachute, a drogue chute and a deployment bag in a split cardboard container.

k. A *compression pad,* located between the parachute and the end cap, assures that all the assemblies are firmly held in place.

l. An aluminum *end cap* seals the base end of the flare.

3-3. Tabulated Data

Diameter (max)	4.87 in
Length (max)	36.0 in
Weight	28 lb
Candlepower (avg)	2 million
Burning time (avg)	210 sec
Fixed delay (nominal)	2 sec
Fixed delay (min)	1 1/2 sec
Rate of descent	7.5 fps

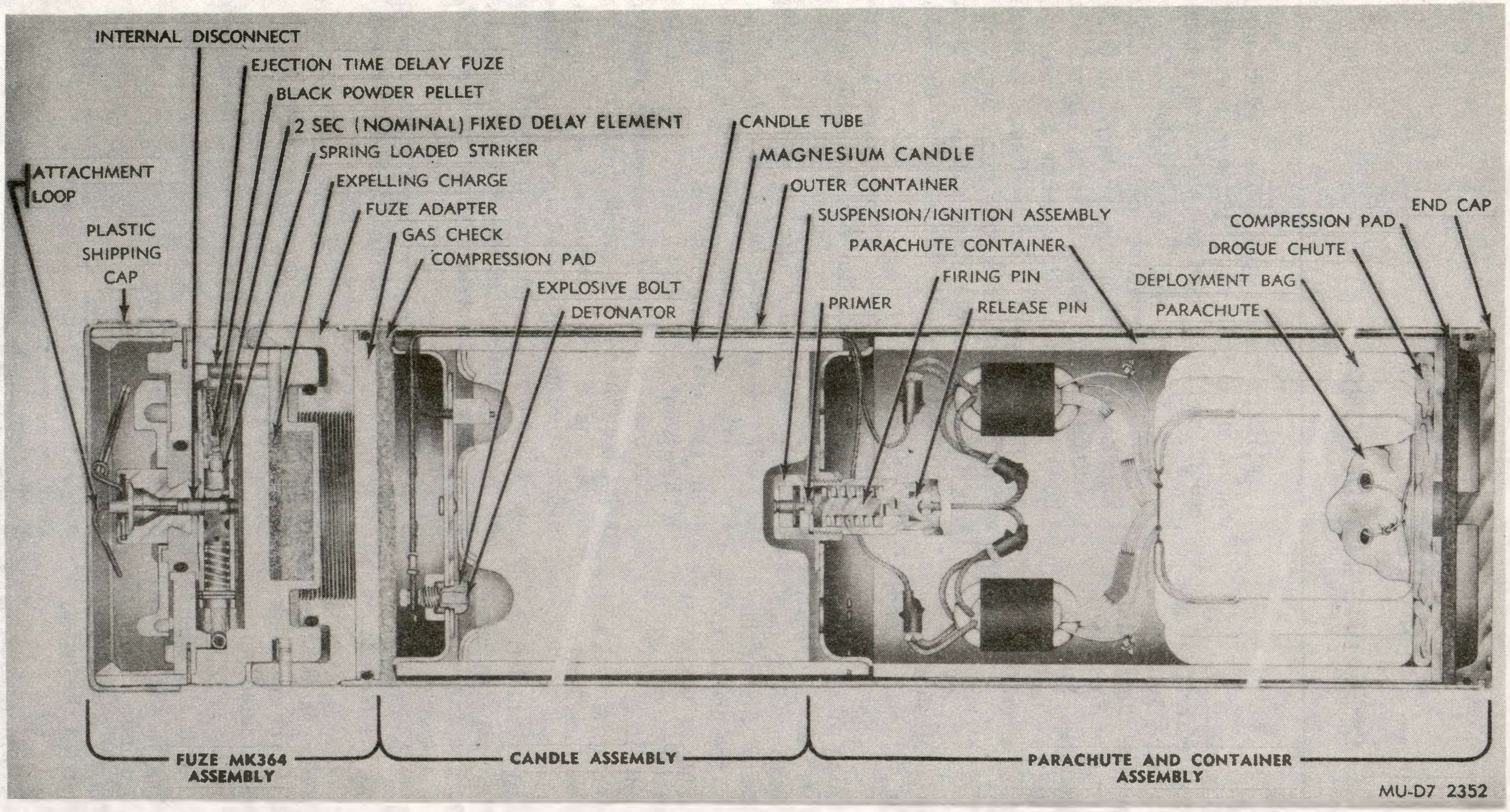

Figure 3-1. Aircraft parachute flare Mk45, cross-section.

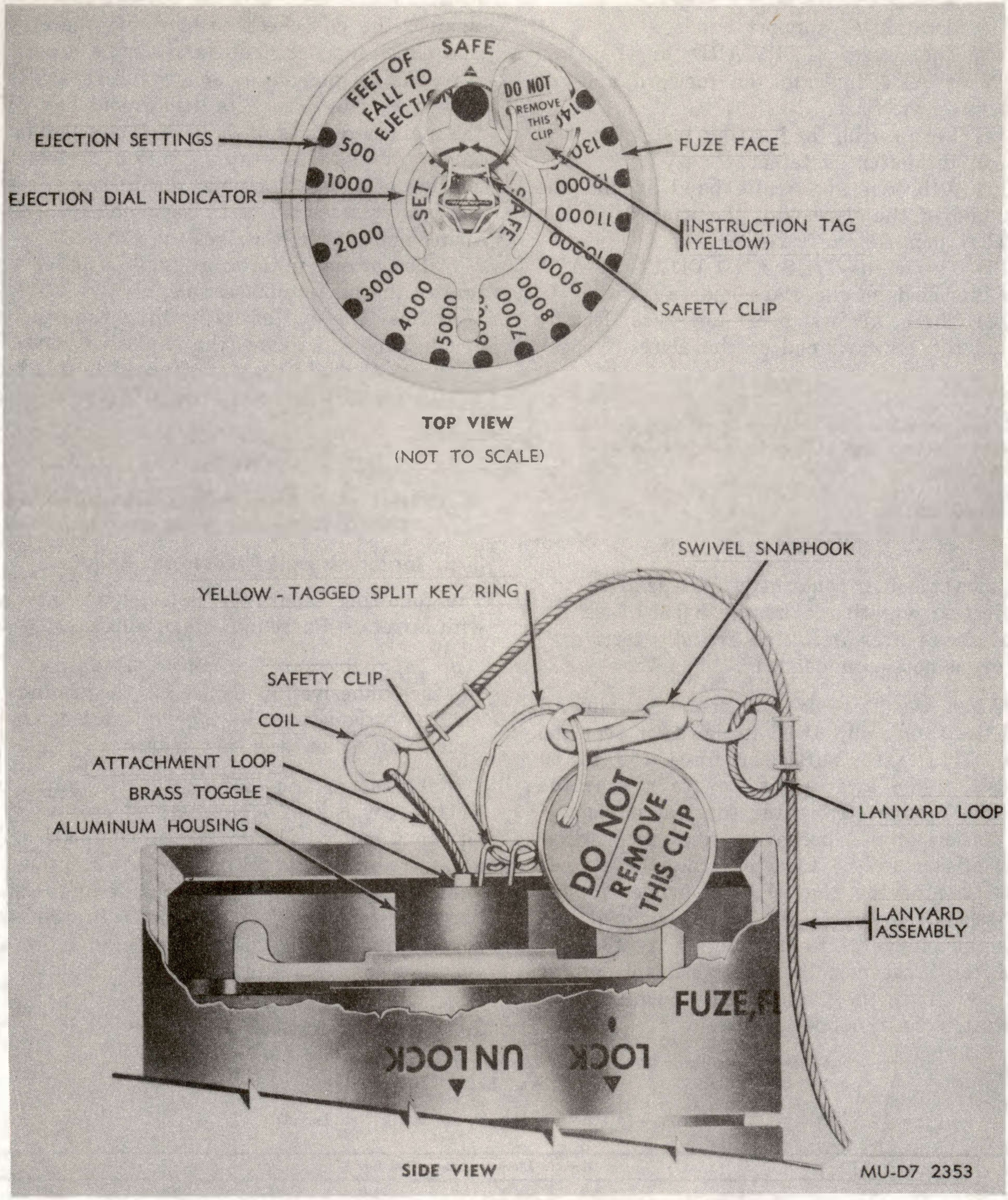

Figure 3–2. Flare Mk45, fuze mechanism and lanyard.

3–4. Packing and Marking

a. Packing. Flares are packed two each in a polystyrene container secured by tape. Each flare is a sealed unit.

b. Marking. Flares and/or packings bear the following information:

(1) Nomenclature and model designation.
(2) Federal Stock Number.
(3) Lot number.
(4) DOD number.
(5) Loading date.
(6) Manufacturer's name or symbol.

(7) Loading facility.

(8) Inspector's acceptance stamp.

(9) Location of support bands.

(10) The words FORWARD or UP and DOWN or AFT indicate the forward and aft positions on the flare.

(11) Fuze setting and safing instructions on label on the outer container.

(12) A brown and white band around the lower end of the flare with the word ILLUMINATING printed on it twice.

(13) The words THIS END DOWN or AFT when launched on the flare end cap.

(14) Three arrows over the fuze locking pins on the forward end of the flare.

NOTE

Follow procedures as outlined in paragraph 3–8, below. Setting and safing instructions on flare are incomplete.

3–5. Functioning

WARNING

Since the outer container falls free after ejection, creating a missile hazard, use of flares over inhabited friendly territory is not recommended.

a. When the flare is launched, the lanyard snaps the safety clip from its position over the toggle. This exerts sufficient force (30 to 60 pounds) on the attachment loop to release the internal disconnect from the fuze mechanism.

b. Release of the disconnect frees the spring-loaded striker in the fuze to strike the primer in the base of the plunger. The primer ignites the 2-second (nominal) fixed delay element and drives the plunger into the time delay fuse.

c. After 2 seconds, the delay element ignites black powder in the plunger. The burning powder ignites the time delay fuse.

d. The expelling charge is ignited by the time delay fuse. Thus, sufficient pressure is exerted against the gas check to blow off the end cap and expel the parachute and candle assemblies.

e. The drogue chute deploys and separates the main parachute from its deployment bag. When the main parachute opens, it exerts a pull on the cables of the suspension/ignition system. The shorter of the cables pulls the release pin from the igniter assembly. This cocks and releases the firing pin so that it strikes the primer.

f. The primer initiates an ignition pellet which ignites the magnesium candle.

g. Near the end of its burning time the heat of the candle activates the explosive bolt. (Ten of the 18 shroud lines are attached to this bolt.) Release of these shroud lines collapses the parachute.

NOTE

Collapse of the parachute allows the burned out flare to fall rapidly to the ground.

3–6. Materials and Accessories Required

The following separately issued items are used with Aircraft Parachute Flare Mk45:

a. Tape, Pressure Sensitive, Adhesive. This two-inch adhesive tape is used in the arming procedure. Although green tape is most commonly issued, the color does not matter.

b. XM164 Static Line, Flare. Static Line XM164 consists of eight parallel steel-wire cables in a molded plastic sleeve. The ends of the wires are swaged to fittings which accept swivel-jointed snaphooks. The flat contour of the static line affords a low floor profile to prevent accidental tripping and the plastic coating prevents abrasion to the aircraft transom.

3–7. Fuze Setting Table

Table 3–1. Approximate Release Altitudes for Ejection at 2500 Feet Above Ground Level.

(Altitudes—In Thousands—are at Mean Sea Level)

Fuze Settings	Ground Elevation above Sea Level							
	0	1.0	2.0	3.0	4.0	5.0	6.0	7.0
500	3.0	4.0	4.9	6.0	7.1	8.1	9.1	10.1
1,000	3.4	4.5	5.5	6.5	7.6	8.6	9.7	10.7
2,000	4.5	5.6	6.7	7.7	8.8	10.0	11.0	12.2
3,000	5.6	6.7	7.8	9.0	10.1	11.3	12.5	13.6
4,000	6.5	7.7	8.9	10.1	11.3	12.5	13.8	15.1
5,000	7.4	8.6	9.9	11.1	12.4	13.6	15.0	16.4
6,000	8.2	9.5	10.8	12.1	13.5	14.8	16.2	17.5
7,000	9.1	10.4	11.8	13.1	14.5	15.9	17.4	19.0
8,000	10.0	11.4	12.8	14.3	15.6	17.1	18.3	20.4
9,000	10.9	12.4	13.8	15.3	16.8	18.4	20.1	
10,000	11.8	13.3	14.9	16.4	18.1	19.8		

Table 3-1. Appropriate Release Altitudes for Ejection at 2500 Feet Ground Level—Continued.
(Altitudes—In Thousands—are at Mean Sea Level)

Fuze Settings	Ground Elevation above Sea Level							
	0	1.0	2.0	3.0	4.0	5.0	6.0	7.0
11,000	12.9	14.4	16.0	17.7	19.4			
12,000	13.9	15.5	17.3	19.0				
13,000	15.0	16.7	18.5	20.5				
14,000	16.2	18.0	20.0					

Example: If the target is 1,000 feet above sea level and fuze is preset at 3,000 feet of fall, launch altitude is 10,100 feet.

3-8. Operation under Usual Conditions

This paragraph covers arming, stowage on aircraft, and launching techniques used with Aircraft Parachute Flare Mk45.

a. Precautions.

(1) Do not use flares with cracked, dented or deformed outer containers.

(2) Unauthorized removal of fuzes under any circumstances is prohibited. Do not attempt to remove damaged fuzes from flares. Have flares containing damaged fuzes disposed of by authorized munitions personnel only.

(3) Observe firing temperature limits of +145°F. and -65°f.

(4) Avoid unseating safety clip. If safety clip becomes unseated, secure it in toggle housing groove before proceeding. While clip is out, avoid pulling lanyard. A pull on lanyard of 30 pounds can cause fuze to function. If fuze is set at any delay setting, such pull will cause outer container and candle to separate violently after permanently inoperable.

(5) If flare is accidentally ejected on ground, wind force of 35 knots will cause drogue chute to remove deployment bag and release main parachute. Attempt to keep parachute from opening. Cut shroud lines and dispose of candle tube. If parachute opens accidentally, deflate by holding parachute itself. *Do not* hold candle tube. A 60-pound pull on shroud lines may actuate candle igniter. The parachute could drag *unrestrained* candle tube without causing ignition, providing pull on candle does not exceed 60 pounds.

(6) Require crewmen engaged in launch operations to wear harness and be secured to aircraft by safety line.

b. Preparation for Use.

CAUTION

Have arming and preparation of flares performed by trained, experienced personnel only.

(1) Remove flare from packing container.

(2) Remove plastic cap (fig. 3-3) from fuze end of flare.

Figure 3-3. Removal of cap and lanyard assembly.

NOTE

If flare is shipped with lanyard attached, simply uncoil lanyard, omitting steps (3) and (4), below, and continue with step (5). If lanyard is not attached, accomplish steps (3) and (4) before continuing with step (5)

(3) Remove and uncoil lanyard. Remove lanyard retainer and retain for replacement if flare is not expended.

(4) Connect coil on end of lanyard to attachment loop and toggle in fuze (fig. 3-4).

(5) Using forefinger of right hand and thumb of left hand, set fuze dial by turning clockwise to desired setting (fig. 3-5). (See fuze setting table, paragraph 3-7.) A spring-loaded detent holds dial at set position and aids in setting fuze in darkness—engagement of detent can be felt easily by operator.

(6) Extend lanyard over edge of fuze and secure with a 15 1/2 inch strip of tape to outside of fuze case. Leave lanyard loop and swivel

Figure 3-4. Attachment of coil to attachment loop on fuze.

snaphook just above edge of fuze (fig. 3-6), in line with yellow-tagged key ring on safety clip.

(7) Replace plastic cap, holding lanyard inside cap (fig. 3-7).

(8) Coil remainder of lanyard around outer container and tape in place (fig. 3-8).

(9) Using grease pencil, mark ejection fuze setting on body of flare.

NOTE

Flare is now ready for loading in interior of fixed-wing or rotary-wing aircraft.

c. Operation.

WARNING

Require crewmen engaged in hand launch operations to wear harness and be secured to aircraft by safety line. Do not snaphook to yellow-tagged key ring until just before launching flare.

NOTE

Loading of flares aboard aircraft will be performed by trained personnel only.

(1) Secure flares adequately to prevent movement during flight.

(2) Attach 4-foot static line to cargo tiedown near launch door.

(3) Remove tape securing lanyard to outer container and uncoil lanyard. Stick tape to side of flare case.

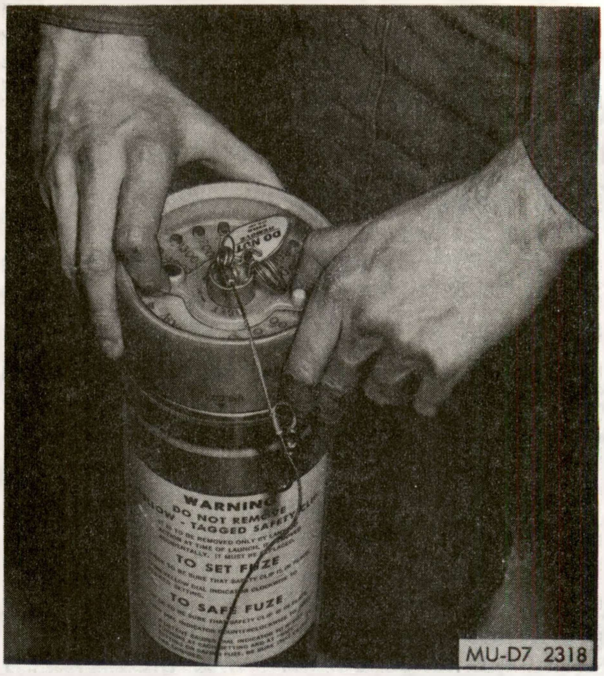

Figure 3-5. Setting fuze.

Figure 3-6. Taping lanyard to fuze case.

(4) Attach free end of static line to lanyard (fig. 3-9).

WARNING

Exercise extreme caution to avoid pulling safety clip during next step. If safety clip is pulled, toss flare from aircraft immediately.

(5) Remove plastic cap. Attach swivel snaphook to yellow-tagged key ring (fig. 3-10) by

Figure 3-7. Replacing plastic cap.

holding ring firmly and pressing down on ring with snaphook.

CAUTION

Flares which hit skid of helicopter may fail to function.

(6) Throw flare from aircraft (fig. 3-11), fuze end last, assuring that flare clears aircraft.

(7) Retrieve static line and remove lanyard debris. Retain for disposal after landing.

d. Prepared for Use but Not Launched. Flares which were prepared for use but not launched will be returned to their original condition as follows:

(1) Remove plastic cap.

(2) Assure that fuze safety clip is secure.

(3) If flare has been hooked up for launch, assure that lanyard swivel snaphook is disconnected from safety clip key ring.

(4) Return fuze setting dial, counterclockwise, to SAFE.

(5) Remove tape securing lanyard to outer case and uncoil lanyard.

(6) Remove tape securing lanyard to outside of fuze.

(7) Install lanyard retainer and recoil lanyard inside of fuze well; replace plastic cap.

(8) Remove or block out fuze setting marked on outer container with grease pencil.

Figure 3-8. Taping coiled lanyard around outer container.

(9) Repack serviceable flares, in accordance with instructions in chapter 4. Use repacked flares first in subsequent launchings.

3-9. Operation under Unusual Conditions

Operation of this flare under unusual conditions is the same as under normal conditions, with the following exception:

During operation in Arctic environments, preparation procedures must be accomplished in warm structure to facilitate fuze setting and taping procedures. At extremely cold temperatures, the fuze dial may become frozen in place, making fuze setting difficult.

Figure 3-9. Static line attached to lanyard.

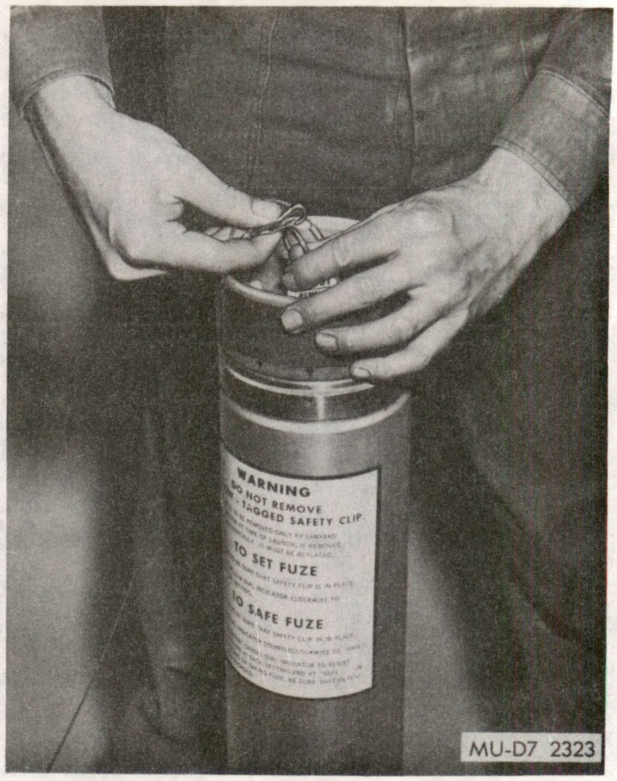

Figure 3-10. Attaching swivel snaphook.

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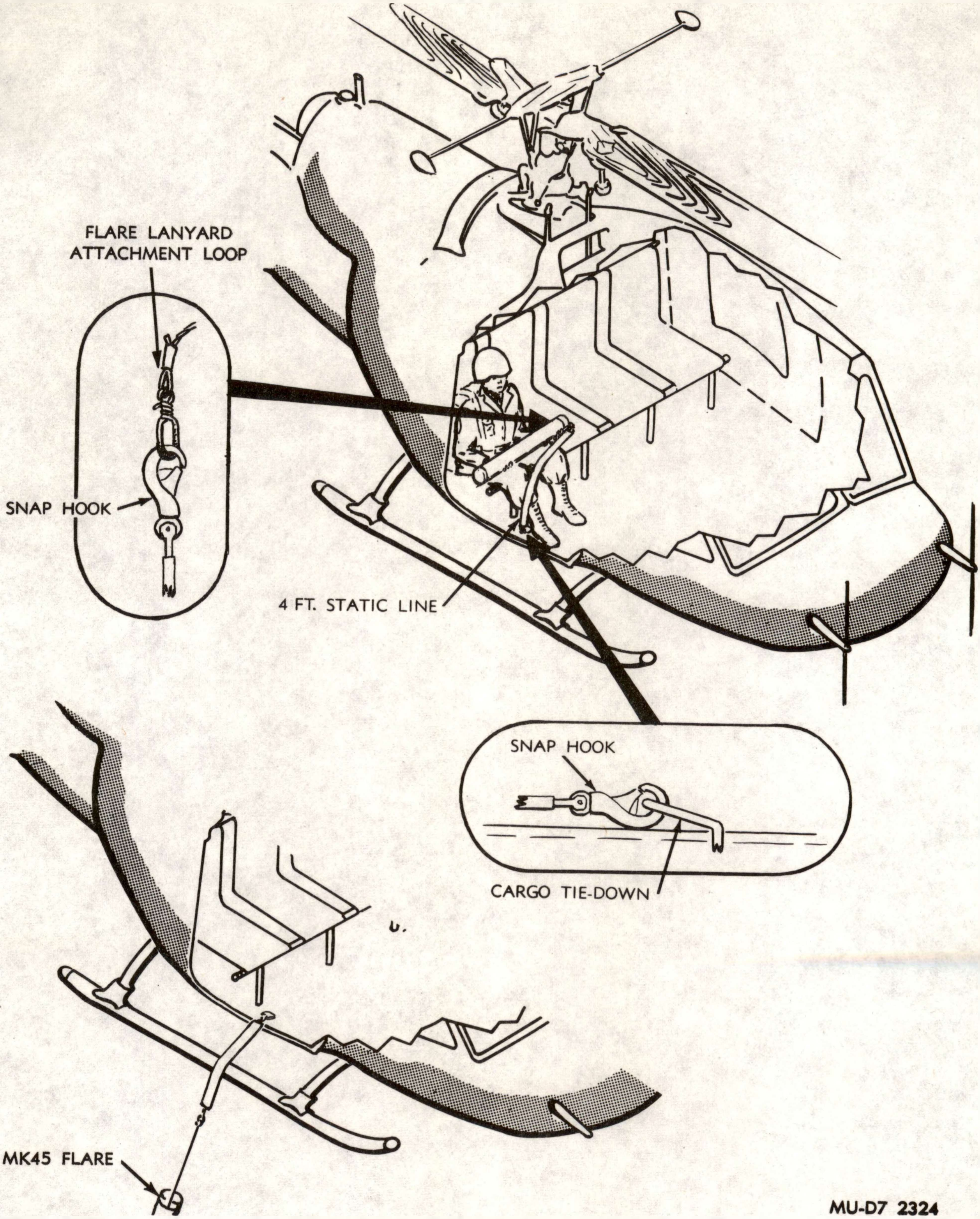

Figure 3–11. Tossing flare from helicopter.

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CHAPTER 4

MAINTENANCE INSTRUCTIONS

Section I. SERVICE UPON RECEIPT OF METERIEL

4-1. Precautions

Flares will be handled by trained, experienced personnel only. Flares are capable of withstanding normal handling but, like other pyrotechnic items, should not be subjected to excessively rough treatment.

4-2. Inspection

a. Inspect shipping containers for the following:

(1) Signs of excessive damage or rough handling.

(2) Signs of excessive moisture.

b. Return excessively damaged containers to depot without unpacking.

c. Set aside excessively moist containers for thorough inspection of contents after unpacking.

4-3. Unpacking and Packing

a. Unpacking.

(1) To open plastic containers, cut tape along seams, being careful not to damage container. (Do not use tools or attempt to pry lid open.) Lid should lift off easily.

(2) Remove flare and set container aside for reuse.

b. Packing.

(1) Replace flare in container.

(2) Replace lid of plastic container and tape along seam.

(3) Mark container to indicate that contents will be issued prior to materiel not previously unpacked.

Section II. MAINTENANCE

4-4. General

The following procedures will be performed subsequent to unpacking.

4-5. Precautions

a. Avoid unseating safety clip. If safety clip becomes unseated, secure it in toggle housing groove before proceeding. While clip is out, avoid pulling lanyard. A pull on lanyard of 30 pounds can cause fuze to function. If fuze is set at any delay setting, such pull will cause outer container and candle to separate violently after the delay; if set on SAFE, fuze will become permanently inoperable.

b. If flare is accidentally ejected on ground, wind force of 35 knots will cause drogue chute to remove deployment bag and release main parachute. Attempt to keep parachute from opening. Cut shroud lines and dispose of candle tube. If parachute opens accidentally, deflate by holding parachute itself. *Do not* hold candletube. A 60-pound pull on shroud lines may actuate candle igniter. The parachute could drag *unrestrained* candle tube without causing ignition, providing pull on candle does not exceed 60 pounds.

4-6. Procedures

a. Inspect flares as follows:

WARNING

Removal of fuze from flare is prohibited.

(1) Inspect flares for dents, cracks or other damage to outer container.

(2) Place damaged flares aside for disposition by authorized munitions personnel.

(3) Remove plastic fuze cap.

(4) Assure that fuze is locked in place on flare.

NOTE

In the locked position, the arrows under the lock markings on the fuze will line up with the arrows covering retaining pins in the flare body. If the fuze is not locked, be sure that is set on SAFE. Hold the flare stationary and turn fuze clockwise until it locks

(5) Assure that safety clip is in place and fuze dial is set on SAFE.

WARNING

If fuze dial is not set on SAFE and safety clip is missing, a pull of 30 pounds can cause ejection of parachute and candle from outer container. Outer container can create serious missile hazard at distances up to 150 feet.

(6) If fuze dial is not set on SAFE and safety clip is not installed, install safety clip and return dial to SAFE.

(7) On completion of inspection, repack serviceable flares for local storage.

b. Inspect accessories as follows:

(1) Inspect static lines for fraying, damage or other conditions which would render item unserviceable.

(2) Replace serviceable items in original containers marked to indicate contents.

THE VALUE OF PERFORMANCE.

NORTHROP GRUMMAN

LUU Parachute Flares

LUU-2D/B Illuminating Flare and LUU-19B/B Infrared Flare

Northrop Grumman's LUU parachute flares support warfighters, pilots, and search and rescue personnel engaging in low-light operations. When used in conjunction with night vision equipment, infrared illumination allows personnel to see nighttime terrain, the ocean, and the battefield as never before.

LUU flares are used by U.S. and international military forces. For the last 40 years Northrop Grumman has continually developed and integrated improvements and modifications to enhance performance and reliability.

LUU-2D/B Illuminating Flare

The LUU-2D/B parachute flare supports visible nighttime target illumination and rescue operations. The LUU-2 D/B is used by the governments of 25 countries to provide aircraft-deployed illumination. The LUU-2D/B produces about 1.8 million candlepower of visual illumination for four to five minutes.

LUU-19B/B Infrared Flare

Like the LUU-2D/B, the LUU-19B/B is used worldwide and provides covert illumination in the near-infrared (IR) spectrum with virtually no visual signature. The LUU-19 B/B illuminates a diameter of 6,000 meters for seven minutes.

Facts at a Glance

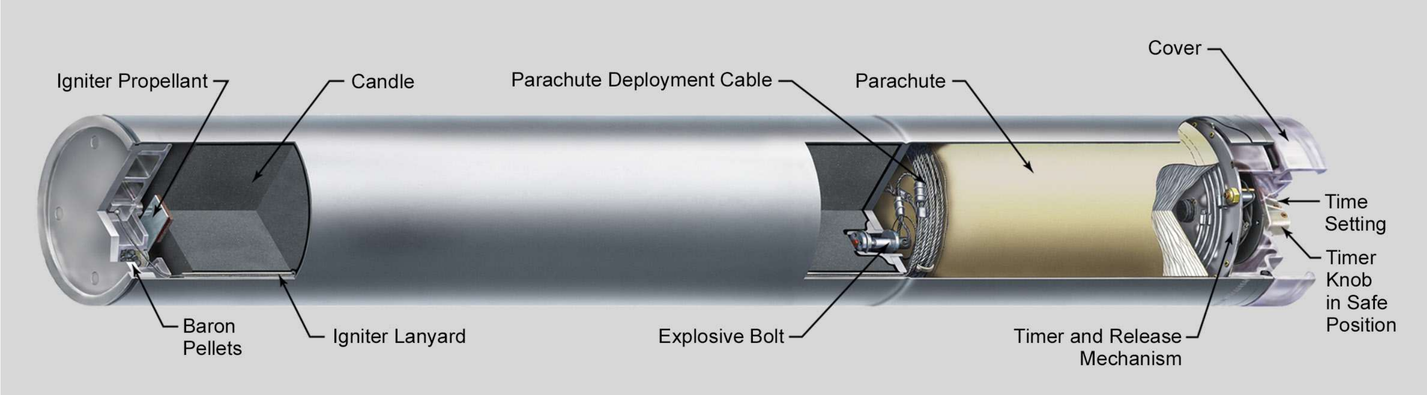
Compatible with all standard flare launching systems used on rotary- and fixed-wing aircraft

Deployable from LAU-74 cargo aircraft launchers, aircraft wing-mounted racks, and the SUU-25, -42, and -44 series launchers

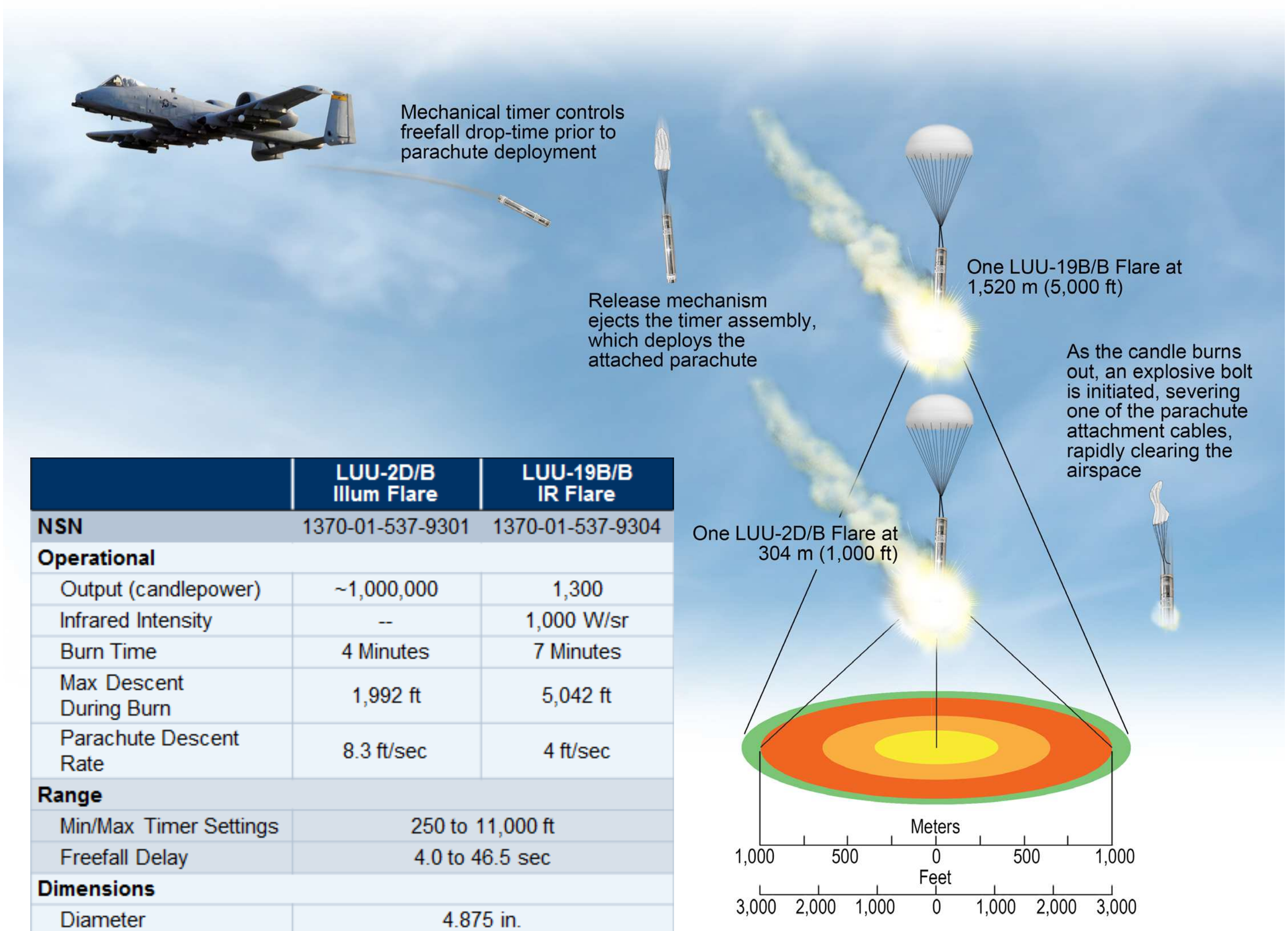
Hand-launchable

Safety features include:

- Non-detonable illuminant
- Extremely shock resistant
- Safe position on the timer
- Out-of-line ignition system
- Multi-step ignition process



Operational Sequence



	LUU-2D/B Illum Flare	LUU-19B/B IR Flare
NSN	1370-01-537-9301	1370-01-537-9304
Operational		
Output (candlepower)	~1,000,000	1,300
Infrared Intensity	--	1,000 W/sr
Burn Time	4 Minutes	7 Minutes
Max Descent During Burn	1,992 ft	5,042 ft
Parachute Descent Rate	8.3 ft/sec	4 ft/sec
Range		
Min/Max Timer Settings	250 to 11,000 ft	
Freefall Delay	4.0 to 46.5 sec	
Dimensions		
Diameter	4.875 in.	
Length	36 in.	
Weight	30 lb	

For more information, contact:

Northrop Grumman Specialty Products
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Munitions Effectiveness

FLARE EFFECTIVENESS FACTORS: A GUIDE TO IMPROVED UTILIZATION FOR VISUAL TARGET ACQUISITION

TARGET ACQUISITION WORKING GROUP REPORT

Joint Technical Coordinating Group for Munitions Effectiveness

FO 8635-75-C-0004

FLARE EFFECTIVENESS FACTORS: A GUIDE TO IMPROVED UTILIZATION FOR VISUAL TARGET ACQUISITION

TARGET ACQUISITION WORKING GROUP REPORT

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November 1973

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1 – 84	0

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PREFACE

This technical report documents an "in-house" survey conducted from September 1972 to March 1973 by the Aerospace Medical Research Laboratory. The work is part of a joint Services program on air-to-ground target acquisition. The research was undertaken in response to a request from the Target Acquisition Working Group (TAWG) established by the Joint Tactical Coordinating Group for Munitions Effectiveness under the Joint Munitions Effectiveness Manual/Air-to-Surface. The request was for the publication of information which will become part of the Joint Munitions Effectiveness Manual and which pertains to the effective planning and execution of flare missions for unaided air-to-ground visual target acquisition.

Current TAWG tasks include the definition of problem areas in airborne forward air controller operations, the description and effectiveness estimation of target markers, research on target acquisition by flarelight, summary and synthesis of existing target acquisition field test data, and the description and evaluation of mathematical models of the visual target acquisition process.

The scope of the study was broadly defined by the TAWG steering committee composed of Ronald Erickson, Chairman (Naval Weapons Center), Major Robert Hilgendorf, Co-chairman (Wright-Patterson Air Force Base), Dr. Howland Bailey, Mathematical Model Subgroup Chairman (Rand Corp.), Ronald Bruns (Naval Missile Center), V. Darryl Thornton (Elgin AFB), Lt Col C. E. Waggoner (Brooks AFB), and Paul Amundson (Naval Weapons Center). The work was conducted by the TAWG Flare Research Subgroup. Dr. Shelton Macleod (Aerospace Medical Research Laboratory) was the principle investigator. The study was technically reviewed by other members of this Subgroup.

The aid of the following individuals in the preparation of this report is especially acknowledged: Mr. Carl W. Lohkamp, Research and Development Department, Naval Ammunition Depot, Crane, Indiana, reviewed the manuscript, provided most of the ideas for the introductory Summary of Applied Principles, and rewrote the section on Candle Composition; Mr. Robert B. Davis, Pyrotechnics Division, Picatinny Arsenal, Dover, New Jersey, reviewed the manuscript and provided a useful critique on the inadequacies of current pyrotechnic illumination standards.

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INTRODUCTION

BACKGROUND

This document is responsive to a request from the Target Acquisition Working Group (TAWG) of the Joint Tactical Coordinating Group for Munitions Effectiveness for the publication of information which will become part of the Joint Munitions Effectiveness Manual and which pertains to the effective planning and execution of flare missions for unaided air-to-ground visual target acquisition. The following ground rules have been adopted in interpreting TAWG's request and organizing the contents of this report. The data provided are intended for that community of interest within the Armed Forces which is concerned with research, engineering, planning or operational activities involving the design or deployment of illuminating flares for air-to-ground visual target acquisition.

Ideally this report should be a manual which provides the user with complete information for researching, operating and evaluating current and future illuminating flare systems. However, such a compendium is now virtually impossible to produce, given the existing gaps and limitations of data on flare effectiveness. Sufficient data that are valid, quantitative and applicable to all user needs simply do not exist. Nevertheless, within the past 10 years ground has been broken and a considerable amount of relevant pyrotechnic and visual research has been generated by all three Services. This paper extracts, organizes and evaluates the data of those studies that appear to have immediate or potential user application. Accordingly, a research-centered document has been prepared providing the user with information, guidance and recommendations that are primarily concept oriented rather than hardware oriented. Hopefully, the reader will be able to select, interpret and apply those sections of the report that are relevant to his particular problems.

Certain advantages may be derived from this approach: (a) It systematizes and integrates a wide variety of research efforts, thus increases the degree of impact on current user needs; (b) Rather than limiting the approach to the specific equipments or systems of a particular organization, it permits a broader degree of generality applicable to the needs of many groups within all services; (c) It can result in stronger and more relevant interdependency between researcher and user so that technological needs are better selected, stated and prioritized.

SUMMARY OF APPLIED PRINCIPLES FOR EFFECTIVE FLARE UTILIZATION

Although this report is primarily research oriented, stressing gaps in knowledge and the need for empirically derived information, it would be a mistake to deny the reader those benefits derived from practical experience which govern effective deployment of illuminating flare systems. Such experience has led to certain "rules-of-thumb" which tend to pay off under a relatively wide range of conditions. Some of these working principles will be included herein for the benefit of those readers who participate directly in the planning or operation of flare missions. These points are by no means exhaustive and are given in no particular order. They represent the kind of advice that a seasoned user would give the planner who is learning to deploy a flare system. Despite the likelihood that this advice will be generally beneficial, the

phrase "other things being equal" should be applied to all helpful hints of this type. Subsequent sections of this document will be more concerned with these "other things."

Types of Flare Missions

As pointed out by Davis and Tyroler (1972), there are three general categories of missions into which the use of illuminating flares fall, and most applications are one or a combination of these categories:

1. Fixed Position. Here a predesignated target is at a known location and must be illuminated as a basis for subsequent military action (e.g., strike or damage assessment).

2. Specific area. In this situation a specified area must be illuminated to such a level that, if a known target is present, the observer has a high probability of recognizing it. This tactic is commonly deployed in securing an area against infiltration by enemy troops.

3. Search. In this case one is concerned about finding known targets or targets of opportunity in a relatively large suspect area, e.g., searching for tanks or trucks along a road.

Flare deployment tactics will obviously differ for each of these situations. For effective target acquisition, the number of flares, as well as the amount of illumination required per flare will generally increase progressively (possibly by a factor of two) as one proceeds from the Fixed Position to the Specific Area to the Search Situation.

Multiple Flares

The need for multiple flare deployment (including the selection of number of component units and temporal spacing between them) depends largely upon mission requirements. For the Specific Area and Search Situations, multiple deployment patterns will usually be necessary. Suggested formulae for effective launch cycles under these conditions are given in reports by Blunt and Schmeling (1968 pgs 57–63) and by Starrett (1964). Fixed-Position missions are unlikely to require launching more than two flares the same pass.

Atmospheric Effects

Because cloud formations greatly reduce the probability of target acquisition by scattering and attenuating flare light, every attempt should be made to launch flares over openings in cloud cover or beneath cloud layers.

Even a moderately restrictive meterological condition (i.e., a slight ground haze) which reduces the meterological range by one-half is also likely to reduce the probability of detecting a target by the same amount.

Glare-Angle

The geometry of deployment should be such as to maintain a glare-angle (i.e., the angle formed at the observers eye from respective lines of regard to the flare and the target) larger

than 7°. For smaller glare angles excessive veiling illumuination from the flare will obscure the visual image of the target. In any case the observer should refrain from looking at the flare, since this can significantly impair his night vision for several minutes. During this time his ability to acquire targets will be reduced.

Flare Ignition Altitude

This should generally be kept as low as possible without sacrificing other requirements to (1) prevent glare, (2) maintain a sufficient burn-period to search for the target, and (3) avoid ground-burning. Flares ignited at low altitudes provide less opportunity for wind-drift and enemy-alert before the target is adequately illuminated. Moreover, a relatively low illuminating source, increases the probability of effectively silhouetting the target.

Relative position of Observer, Target and Flare.

If mission requirements emphasize the need for visual target acquisition, it is generally best to drop the flare on the far side of the target from the observer (i.e., back-lighting the target). Under these conditions it is most advantageous to *not* have the observer, target and flare in the same vertical plane. A minimum lateral observer-offset of 15 degrees is recommended.

If, on the other hand, a higher priority is placed on the safety of the observational aircraft, the flare should be dropped between it and the target, thus providing an illuminating shield against hostile detection.

Illuminating Target Background.

Placement of flares should be such as to take full advantage of cues to target detection, i.e., features of the environment (rivers, roads) which are invariably associated with certain types of targets (boats, bridges, vehicles). If, on the other hand, features of the environment constitute clutter (i.e., irrelevant objects such as trees or cattle likely to be confused with targets), the level of flare illumination must be increased to minimize observer-error.

Slant Range Visibility

The probability of recognition approaches an unacceptable level at observer-to-target distances (slant ranges) where the visual angle subtended by the target is less than one minute of arc. A rapid estimation of this limiting distance is given by the formula $D = 3500L$ where D is the observer-to-target distance and L is the largest dimension of the target projected to the eye. At most practical slant ranges it will be virtually impossible for the aircraft observer to identify discrete personnel. Direct sighting of this small a target (which is able to effectively use ground cover) is generally not feasible.

Aircraft Speed

There is generally an inverse relationship (beyond some low limiting speed) between aircraft

velocity and probability of target acquisition. Hence observer aircraft speed should be maintained as slow as possible (within equipment or mission constraints).

Utilization of Wind

Flare light acquisition will generally be unfeasible during periods of exceptionally strong or gusty winds which blow the flarelight off the target. Nevertheless for moderate winds (up to about 20 knots), where altitude profiles of wind velocity are available, flares may be advantageously dropped with wind-drift taken into account so as to drift over the target at the time of most effective illumination or, possibly, to provide effective light while drifting over an extended area.

Wind-Screen Condition

A surprising amount of degradation in the observer's ability to sight targets may be directly attributable to the condition of the wind screen through which he is looking. Accumulated effects of scratches, dirt and grease on this viewing media can reduce light transmission by as much as 50 percent. The transmissivity of the window material is also important and requires checking.

MILITARY APPLICATIONS OF ILLUMINATING FLARES

The deployment of visual illuminating flares is part of a broad class of operations known as Military Pyrotechnics. This has been defined by Hart (1955) as a "category of ammunition employed primarily for the production of light, heat, smoke and sound for such typical nondestructive purposes as battlefield illumination, signalling, marking, tracking, tracing, spotting, ignition, simulation and aerial night photography . . . produced as a result of chemical reactions caused by the application of proper stimuli to chemical elements or compounds alone or in intimate mixtures. Military pyrotechnics are major aids and accessories in tactical operations for communications, warning, reconnaissance and the effective application of destructive firepower, in strategic operations for intelligence, in supporting activities such as rescue operations and troop training, in research and development of rocket powders and propellants, and in exploration of the upper atmosphere."

Within the broader range of pyrotechnics this paper is concerned with the illumination flare, a ground illumination system designed to be air-launched at night and to provide sufficient light over designated areas for specific kinds of military operations to occur. Included here are such diverse activities as navigation, rendezvous, reconnaissance, target marking, ground support, search and rescue, disruption of enemy gunners, terminal guidance, and strike illumination. Note that for special applications flares may be designed to emit invisible irradiation. Here the flare emission enhances the use of infrared night vision aids for target acquisition by providing the required type of background illumination.

TARGET ACQUISITION RESPONSES

Of prime concern in this report is the use of flares for air-to-ground unaided visual target acquisition from observational aircraft. A point worth stressing here is that the required kinds and

levels of target acquisition responses can vary widely depending on the type of military application which the flare-light illumination supports. Thus illuminating a prelocated target places a different visual requirement on the human observer (elicitation of a single preset confirming reaction) than does the illumination of an area under surveillance (which requires search and the possibility of alternative responses). Still another alternative would be the illumination of suspect areas for targets of opportunity, where an observer searches with even less knowledge of what he is looking for. Differing military requirements can also dictate different levels of response specificity. These have been categorized as: (1) Detection—merely locating an unspecified object, (2) Orientation—being able to discern the long and short dimensions of a suspect target, (3) Recognition—sufficient labeling of a target to establish the general class of objects to which it belongs (e.g., tank), (4) Identification—more precise categorization of a target (e.g., an M–15).

In addition to the responses associated with labeling the target, target acquisition may also involve responses for gauging the relative or absolute location or distance of the target with respect to the observer or other points of reference.

Mission requirements for visual target acquisition will also dictate the speeds with which observers must respond and the relative cost of different types of response errors, i.e., errors of location, misidentifications or omissions.

For visual flares (as is the case for all other visual acquisition systems), the effectiveness of the total system, as well as its various components, is based largely on the extent to which system outputs in the form of target acquisition responses satisfy the information acquisition requirements for which the system has been designed. In this case the responding unit is the eye and brain of a human observer.

DESCRIPTION OF FLARE DISPENSING SYSTEMS

As indicated in the Introduction, the approach to be taken in this paper is to provide guidance to tri-service users on flare effectiveness at a generalizable level as opposed to a more specific equipment-centered approach. However, to satisfy the interests of the more operationally oriented reader descriptions will be given in Appendix A of seven flare systems: XM170, M8A1, LUU–2/B, MK45, MK24, LUU–3/B (ATTACK), and MLU–32/B (Briteye). These have been taken from a recent report of the Joint Technical Coordinating Group for Air Launched Non Nuclear Ordinance (JTCG/ALNNO). They are representative of air launched illumination flares for the three services. Table I gives numerical comparisons among these systems with respect to: candlepower, burn-time, descent rate, weight, diameter, length, status and user. However, here it will suffice to merely provide a functional listing of the major components comprising a typical air-drop illumination flare system along with a description of how these fit into the deployment cycle. For illustrative purposes a cross section of the MK–45 showing major flare components is given in figure 1 and an illustration of its deployment appears in figure 2.

The components of a typical flare are housed in a cylindrical container. One of these is a pre-set, time-delay fuse assembly activated by the pull of a launching lanyard. A fuse-setting controls

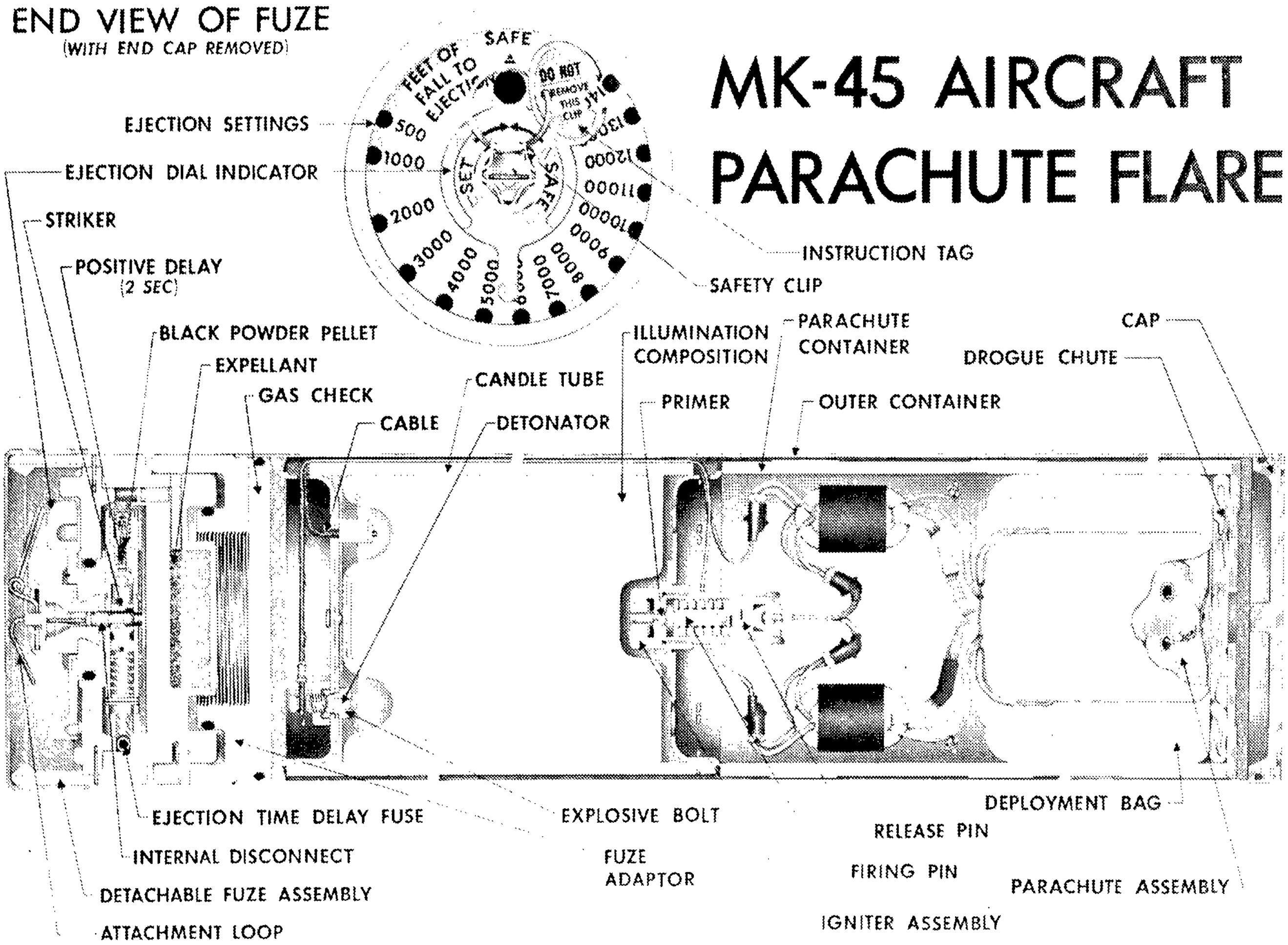

Figure 1. MK–45 Aircraft Parachute Flare

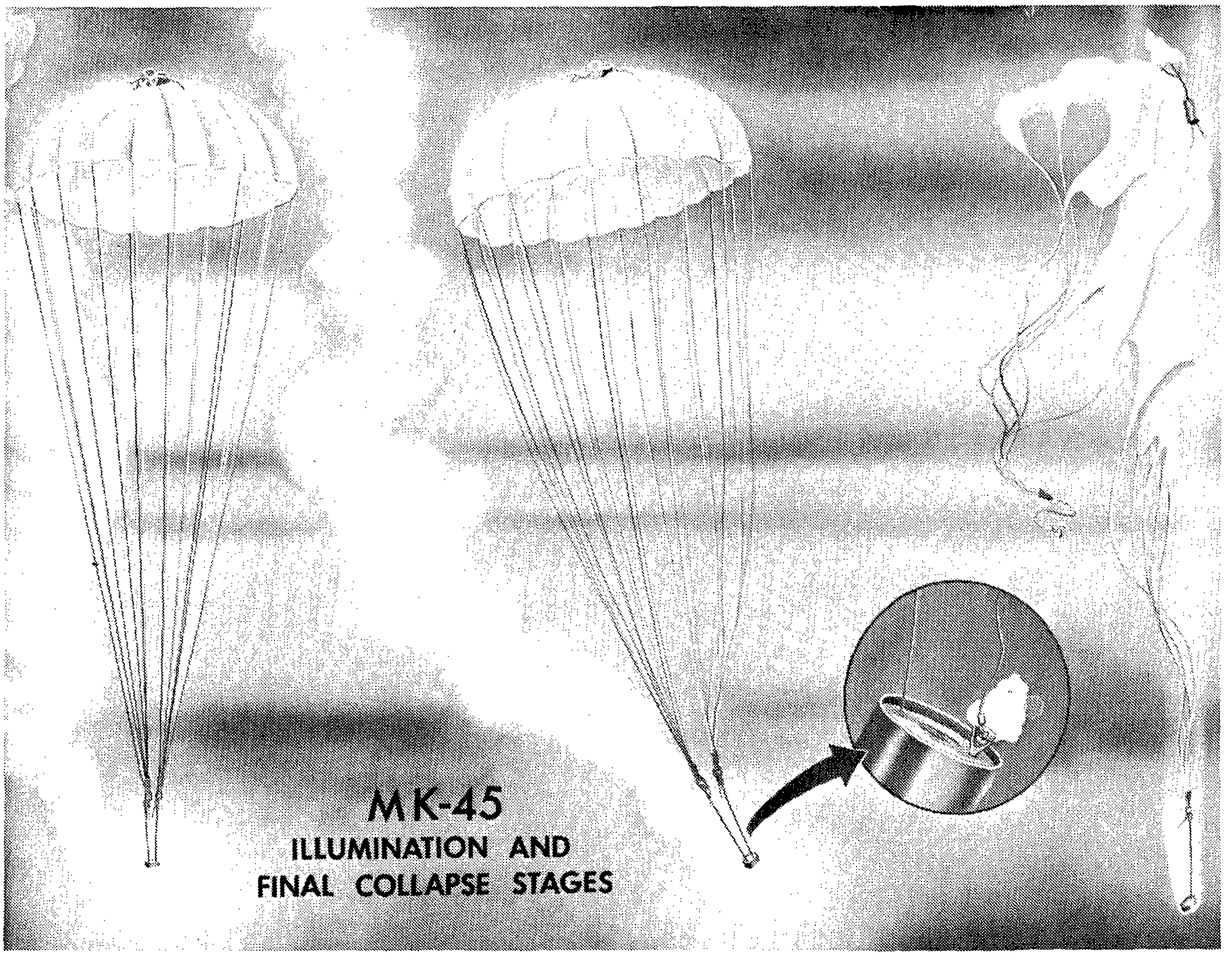

Figure 2. MK–45 Illumination and Final Collapse Stages

footage of fall between launch and the ejection of the candle and parachute assembly (also housed in the container). The pull of the open chute activates an igniter assembly which initiates the burning of a candle (typically 22 inches long by 4.5 inches in diameter). The chute slows and stabilizes the candle's descent thus providing more effective ground illumination. At the end of its burn-time, the candle activates an explosive bolt which releases the shroud lines and causes the parachute to collapse and plummet to the ground.

SUMMARY OF FACTORS CONTROLLING FLARE EFFECTIVENESS

Critical factors which determine the usefulness of flare light for target acquisition will be summarized prior to being discussed in greater detail in the main body of the report.

First, there are the following factors associated with the flare itself: Launch Altitude and Fuse Setting. These jointly determine the ignition altitude of the flare; Candle Size and Composition. This determines the spectral distribution, candlepower and burn-time of the flare; Parachute Suspension System. This determines the descent rate of the burning flare.

Within recent years some flares have also been designed with a surrounding conical shield designed to release smoke upward while it facilitates target acquisition by reducing glare and concentrating the circle of light on the ground.

Flares may also be deployed in multiple launch systems to provide either simultaneous or successive exposures from an aggregate of candles. This not only affords a fail-safe technique against possible duds, but also serves as a pre-planned means of increasing the area, amount and the duration of ground illumination. Controlling factors in multiple launch systems include the number of candles as well as the spatial/temporal drop-intervals between them.

Another parameter affecting light dispersion is the orientation of the falling flare which can be suspended to burn in a downward, horizontal or upward position (the latter option is currently not in accepted use).

Two other environmental factors prevail, being external to the design and deployment of the flare but capable of significantly altering its effectiveness. These are: (a) Wind velocity which if high or gusty, will cause undesirable shifts in ground illumination patterns, but if moderate, may even enhance target acquisition; and (b) Atmospheric effects which, under cloudy conditions, reduce the apparent target-to-background contrast through attenuation and scattering of the flare light.

Many relevant factors are inherently associated with the target (including its shadow) and target background. The following parameters should be mentioned: (a) Brightness-contrast, referring to the ratio of the luminous reflectivity of a target to the reflectivity of its immediate surrounds; (b) Color-contrast, dependent upon spectral reflectivities of both the target and its surrounds; (c) Target size, limiting the distance at which it can be visually resolved; (d) Target shape, an important but largely undetermined factor in target recognition; (e) Target motion, again an undetermined factor which may under specified conditions enhance target

acquisition. In addition to affecting contrast, the (f) Target surrounds may degrade target acquisition if it contains clutter which is confused with the target, or it may enhance target acquisition if it provides cues to target recognition.

Of critical importance to visual flare effectiveness are those factors pertaining to the observer himself. He provides the informational output of the system, but imposes additional constraints on its design in terms of his unique perceptual characteristics and the way he is positioned and interfaced with the illumination system. The following topics in visual perception of interest in this connection are: (a) spatial/temporal visual acuity (b) color vision, (c) light and dark adaptation, and (d) space/time/motion perception. Detailed discussion of these subjects is beyond the scope of this paper. A suggested source for the interested reader is Vision and Visual Perception by Graham et al. (1965).

Nevertheless, so that the reader may better appreciate some of the human factors problems which affect flare-light target acquisition, a description of typical conditions which affect the observer's performance in this situation will be given.

The observer will probably be adapted to a relatively low level of illumination extending downward to 0.01FC. He will be moving at a speed of from 100 to 500 knots at distances from a few hundred feet to several miles from relatively small tactical targets. He is likely to be in voice communication with a Forward Air Controller who has deployed the flare from another aircraft and is directing him toward the target. In addition to inadequate illumination, the following factors will probably degrade his acquisition performance under flare light conditions: (a) stress induced by mission hazards, (b) temporal or spatial disorientation, (c) glare effects, (d) flickering ground shadows, (e) lack of depth cues, and (f) inadequate time to search and identify the target.

SECTION II

RESEARCH APPROACHES

Before engaging in a more detailed analysis of flare effectiveness factors it will first be necessary to describe the different kinds of research facilities where these factors are being evaluated. These facilities are staffed by scientists who are expert in such diverse areas as chemistry, physics, systems analysis, computer technology and behavioral sciences. The major kinds of facilities and their associated research techniques are categorized below. References describing each approach in more detail are also cited.

FLARE TUNNEL

Here the flare is mounted and burned either face-up or face-down in a manner to facilitate smoke removal. Recording photocells are used to measure the candle-power and burn time of alternative candle compositions, sizes, or configurations. An application of this technique is described by Feagans (1967). An illustration of a flare tunnel appears in figure 3.

TOWER FACILITY

Here static tests are performed on the flare while it burns in a fixed and suspended face-down position. Again, photocells are used to measure candle-power. In addition to the kinds of tests performed in the flare tunnel, ground illumination can be directly measured here at various multiaspect angles. This method has been described by Stoval (1966) and is illustrated in figure 4.

FIELD TEST

In this type of test flares are deployed over test ranges under simulated and relatively controlled operational conditions; i.e., using appropriate launch and/or observational aircraft, tactical maneuvers, drop altitudes, deployment of targets, etc. Within the general category of field tests the following alternative techniques are being used.

Pyrotechnic Evaluation Range (PER)

This technique described by Brooks (1970) utilizes a spaced matrix of photo sensors placed on the ground at fixed separations. The sensitivity of each sensor is adjusted so that it can be triggered by a required amount of illumination (usually some fraction of a footcandle). The pattern of response for the entire sensor matrix (covering a ground area of 8100 ft sq) can be observed and recorded by means of a remote real-time electro-optical display. Determination of flare candle-power can also be made by conventional detectors, analogue or by a so-called peripheral technique utilizing the "on" cells at the periphery of the illuminated area [JTCG/ALNO (1971)]. The PER technique has permitted a reliable real-time, photometric intercomparison of ground illumination patterns registered by operational or developmental flares as a function of such factors as altitude, wind-drift, burn-time, or rate of descent. Useful supplementary data are also recorded from observer stations in the form of judgments

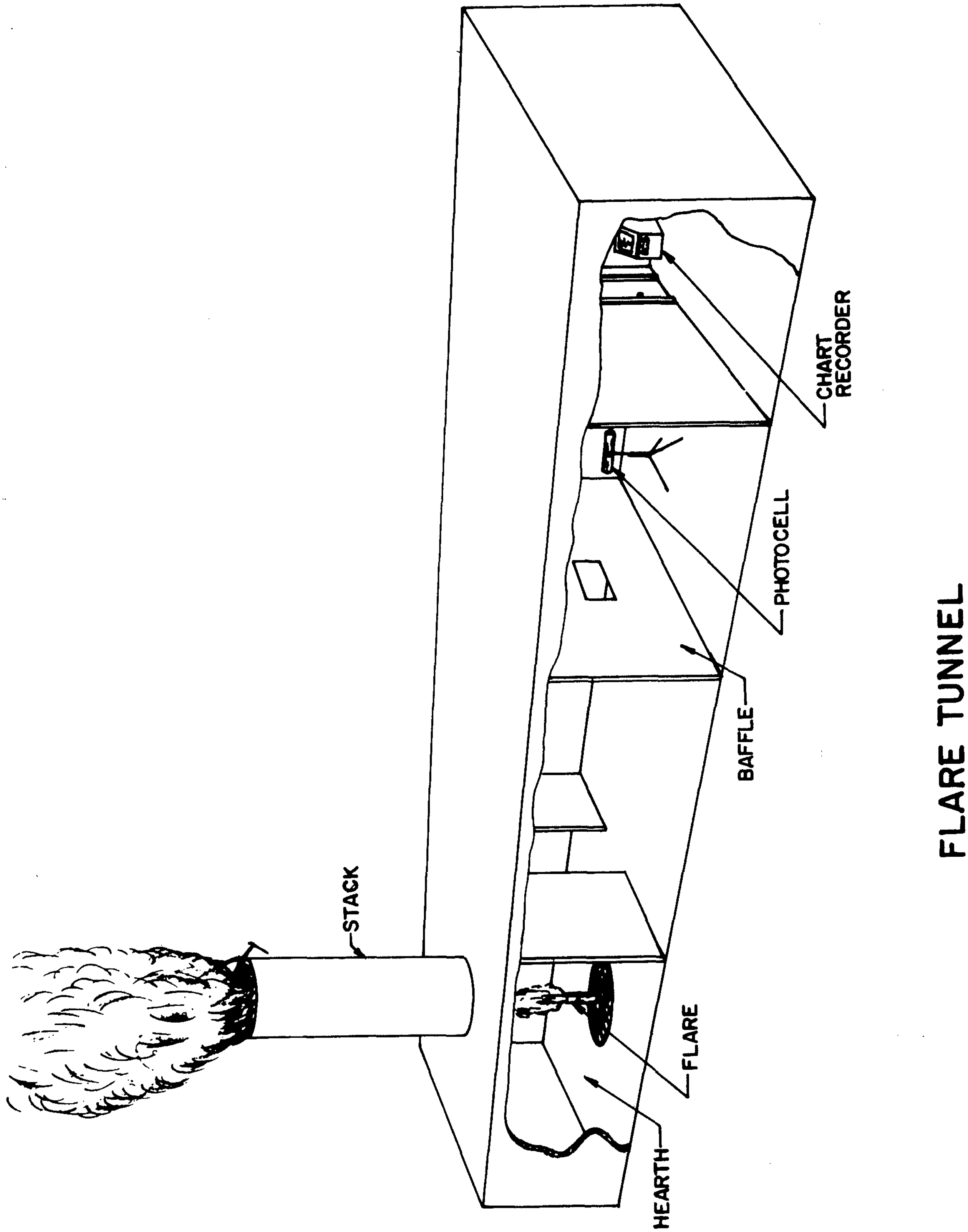

Figure 3. Flare Tunnel

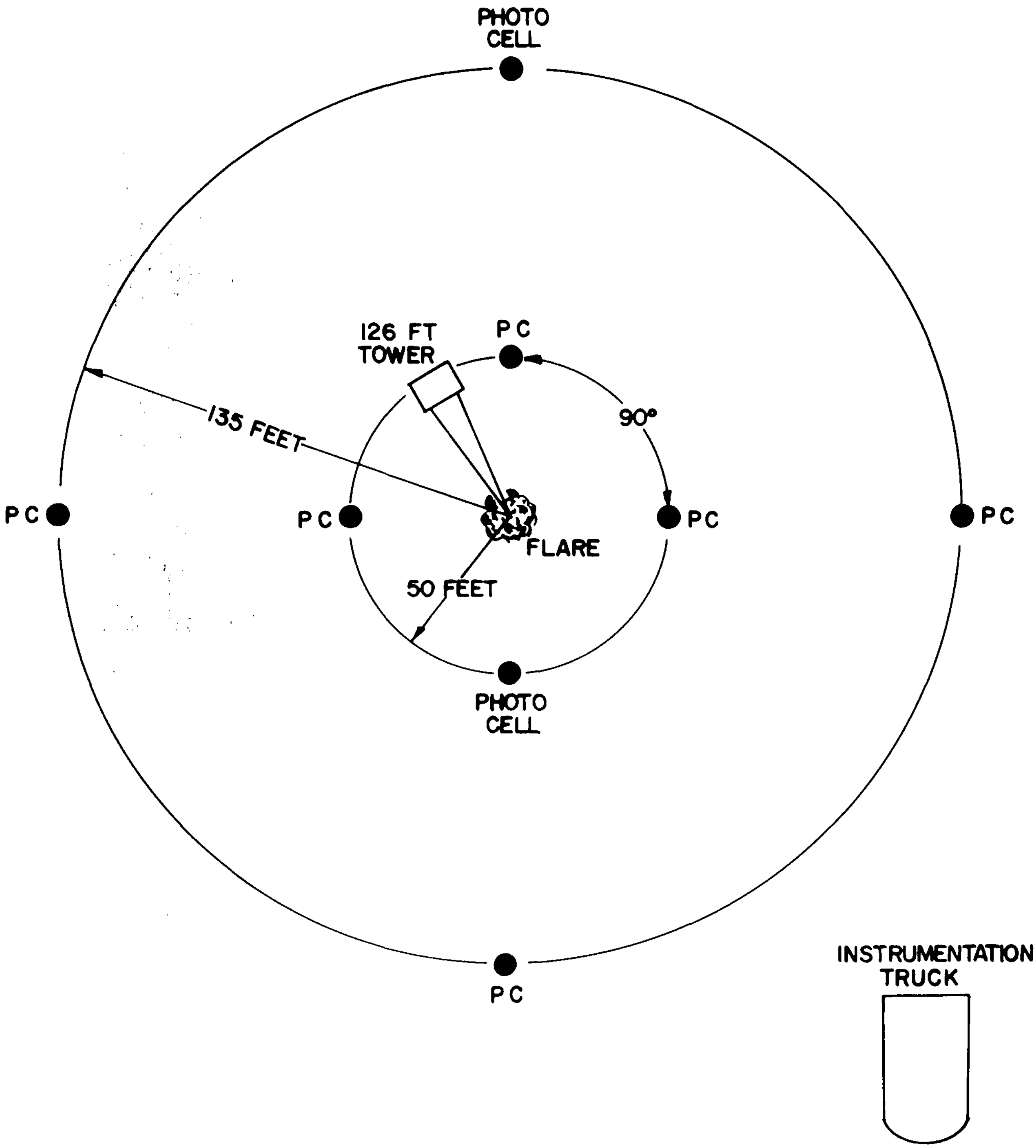

Figure 4. Flare Tower Facility

and time/distance measures. These data apply to such discrete events in the flare cycle as launch, parachute deployment, ignition, descent-rate, burn-time and burn-out. A number of reports on the PER recently installed at Yuma Proving Ground (YPG) have been issued. A good description of the results of YPG tests on six aircraft flares may be found in the report by JTCG/ALNNO (1971). See figure 5 for an illustration of the PER technique.

Observer Opinion Test

Some of the more subjective aspects of flare effectiveness, dealing with pilot/observer flare handler preferences, can be assessed and evaluated through the use of appropriate questionnaires. An example of such a questionnaire described by Craven (1970) has been used by the TAC Special Operation Force in conjunction with a field test of LUU/2B. This is reproduced, along with tallies of pilot and flare-handler responses, in appendix B.

Observer Performance Tests

This type of field-test provides a means of validating other techniques since it deals directly with visual target acquisition and provides quantitative indices of its speed or effectiveness. It requires the deployment of known targets in known positions so that both the accuracy and level of target, identification, as well as the precision of subsequent target-related actions taken by the observer, can be objectively scored and evaluated. The value of this technique depends on the degree to which the types of equipments, target/terrains and scenarios of interest to the user can be effectively integrated. In addition to its relative high cost some disadvantages of this method are: (1) that it may be neither safe nor feasible to incorporate some of the factors (e.g., high wind velocity or minimum visibility) of interest to designers or users, (2) that weather or other flight contingencies may result in unacceptable deviations between the actual and the planned test conditions, and (3) that it is virtually impossible to replicate test conditions with a degree of consistency required for experimental analysis. This method has been used in flare evaluation by Weasner (1965) and Strauss and DeTogni (1962).

TERRAIN-MODEL STUDIES

Although lacking some of the realism offered by field tests, this method provides more research flexibility allowing the investigator (at a small fraction of field-test cost) to simulate, specify, vary, combine and measure a wide variety of alternative flare design or deployment factors with respect to a miniaturized terrain. The terrain is contoured and constructed at a fixed scale which determines its simulated dimensions (as well as those of the targets deployed on it) and the altitudes and viewing distances associated with it. Considerable opportunity for both realism and controlled variation is possible here with respect to: (1) physical and cultural features of terrain; (2) types/deployments of stationary or moving targets; (3) types of flares or flare deployment concepts; (4) position/height/movement of observer viewing stations; (5) wind drift; and (6) ambient illumination conditions. Commensurate with the degree of precise and flexible control over the environmental factors is the capability here for precise measurement of flare intensity, the illumination of targets and their surrounds and observer

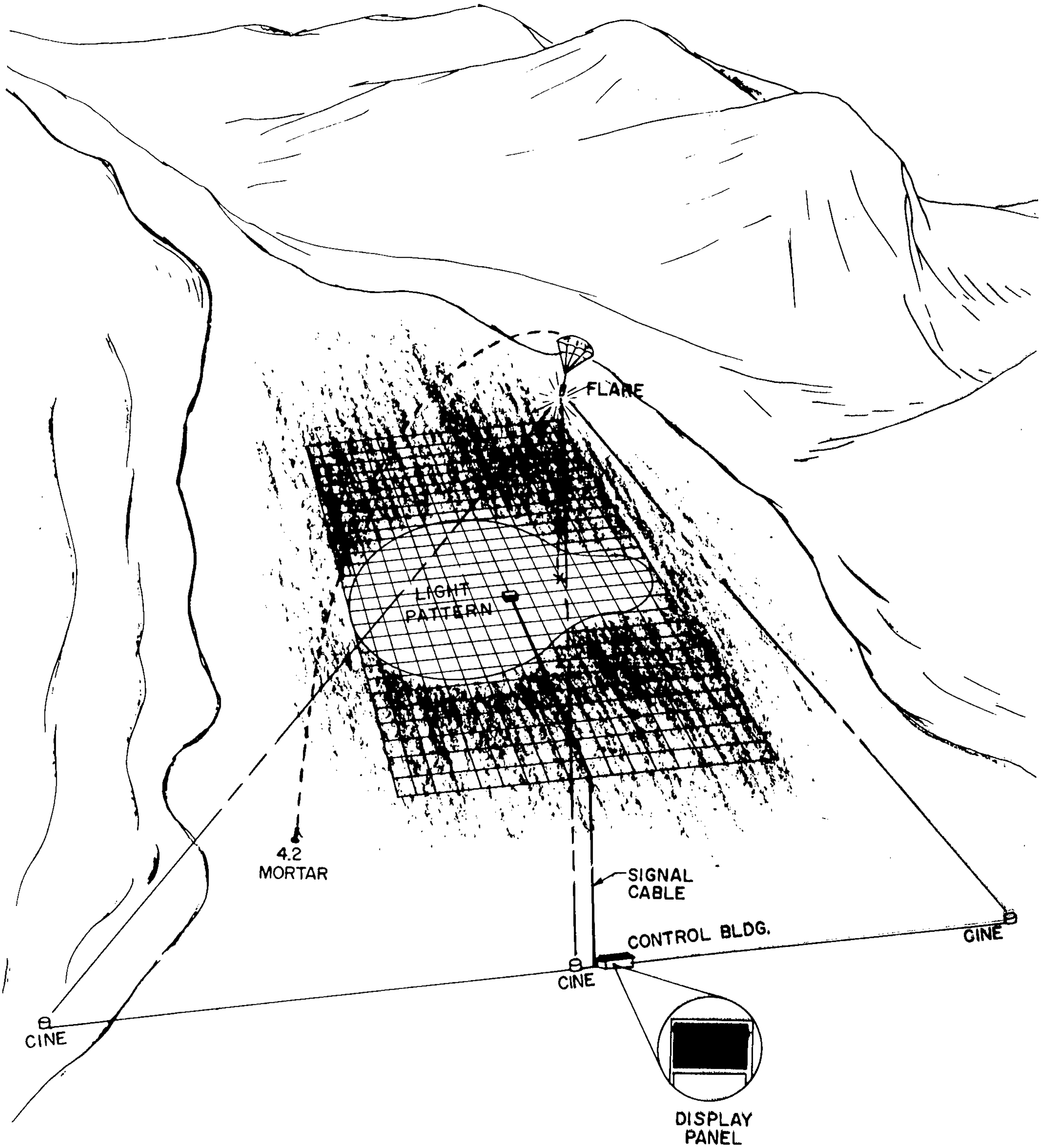

Figure 5. Pyrotechnic Evaluation Range

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response. However, a strong possibility exists with this method for over-simplification and artificiality in incorporating real-world factors. Moreover, there are current state-of-the-art limitations in adequately simulating and measuring certain variables, such as smoke, atmospheric aerosols, or observer stress.

Ideally an in-flight check of the type reported by Hucker (1972) is required to establish the validity of the data developed through terrain modeling research. Flare effectiveness data is now being produced for the Armed Forces with terrain models described by Hilgendorf (April 1971) and Tyroler (1971). A photograph of one of these models is shown in figure 6.

MATH-MODEL STUDIES

One limitation of the previously described techniques lie in their failure to handle economically a sufficient number of critical parameters contributing to the prediction of flare effectiveness. A math modeling approach allows the researcher maximum flexibility in the selection and manipulation of parameters for arriving at predictions on the probability of target acquisition. Here, as has been stated by Kemp (1968), he has the opportunity here to adopt a total systems approach in handling and analyzing (with computer simulation) all relevant factors and assumptions in continuous sets of mathematical operations. Many published predictions on flare effectiveness have come from math modelers. These include a succession of models which have been developed at Crane Naval Ammunition Depot dealing with: Visibility, Bradley (1969); Optimization of the illumination characteristics of the MK45, Laswell (1971); Dynamic evaluation of aircraft parachute flares, Laswell (1972) and Non-isotropic light emissions, Laswell (1972).

Despite the convenience and economy of math models, uncritical acceptance of their predictions is ill-advised. The user of these predictions should remember that they are no more valid than the assumptions and types of data on which they are based. One particular source of weakness in these models is the injudicious use of data drawn from basic research which may be inapplicable to the complexities of target acquisition in the real-world. Another limitation is the inability to account for unique interactions among variables which require empirical determination. In view of these potential drawbacks, math modeling predictions require continuous validation and updating using the most applicable data gathered by the other research techniques.

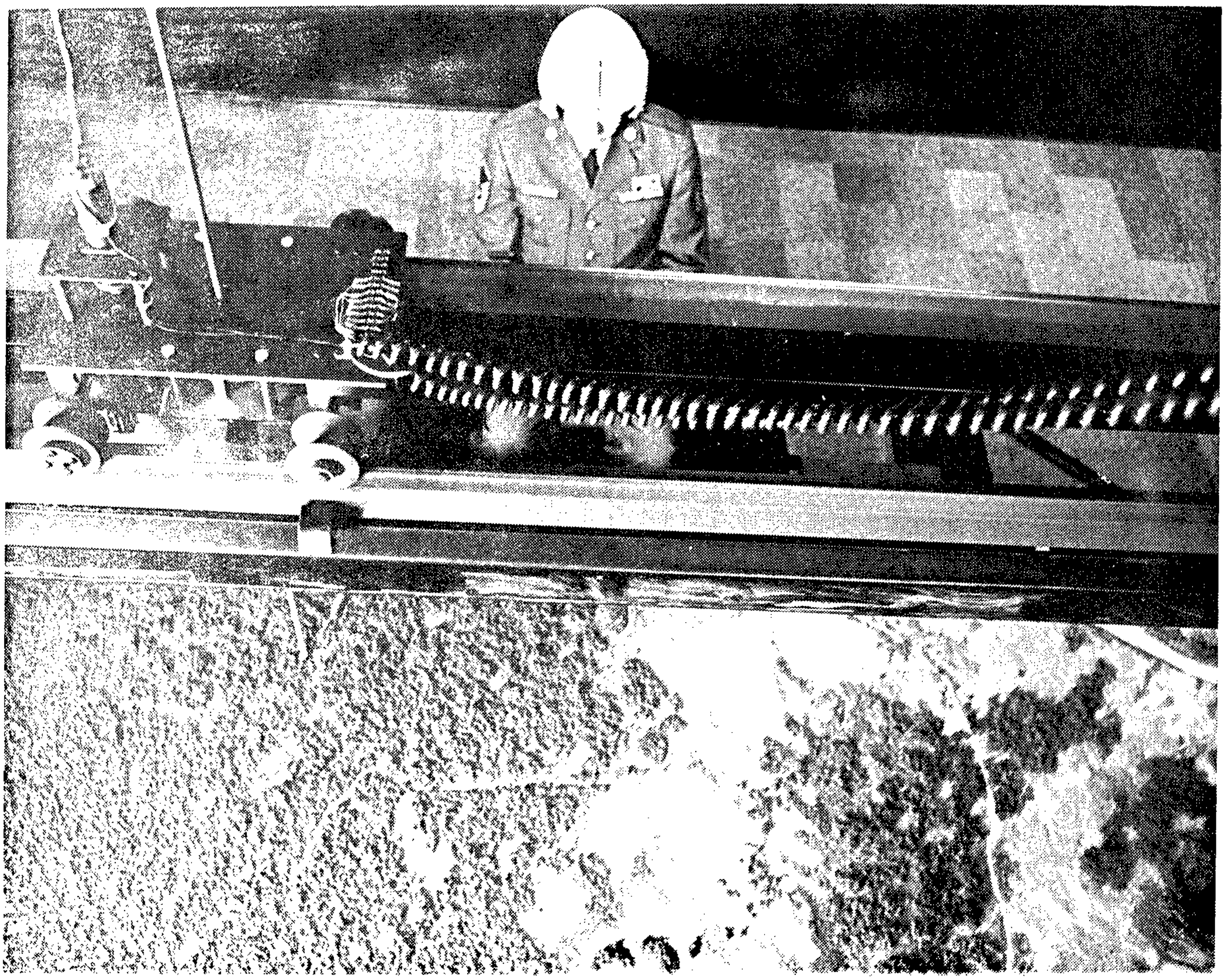

Figure 6. Terrain Model showing Observer and Simulated Flare-Drop Device

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SECTION III

FLARE EFFECTIVENESS FACTORS

Having provided a background for the types of research methodology on which flare effectiveness is based, relevant data from recent studies will now be reviewed. Results and recommendations will be discussed within the context of factors associated with: (a) Candle Composition; (b) Flare Deployment; (c) Wind drift; (d) Atmosphere; (e) Target/Background characteristics; and (f) Observer Position.

CANDLE COMPOSITION

The source of the flare system is the burning candle which, depending on its composition, emits wavelengths of varying intensities from both the visible and invisible regions of the spectrum. Pyrotechnic light sources can be represented in terms of selective radiation by thermally excited molecules superimposed on the radiation of solids and liquids in flame. By appropriately selecting the materials used in compounding the flare candle, it is possible to control the spectral regions at which this emission occurs, thus producing red, yellow, green, blue or white radiation. Ellern (1968) gives typical formulations for each color of flame. For illumination flares, however, an effective spectral distribution is one approximating sunlight. This is presently best obtained from a composition expressed in percentages of magnesium (in powdered form), sodium nitrate and a binder. A flame of high luminosity is provided by selective radiation from the sodium which broadens into a continuum over the visible range from about 500 to 650 nanometers. The visible radiation is due primarily to the broadened sodium D line and a gray body continuum from the condensed species of magnesium oxides. A typical burning flare plume is approximately 10 percent sodium and 50 percent magnesium oxides. A typical spectral flare distribution from the magnesium candle is shown in figure 7. Blunt (1972) gives spectra obtained from different regions of the illuminating flare flame.

From a research point of view, the most efficient pyrotechnic source is one designed to maximize the ratio of selective emission of visible light to the total emission. Data reported by Douda (1968) show that the production of light by the MK24 candle represents about 11 percent of the total energy produced by the flare reaction, which according to Blunt and Schmeling (1968) shows remarkable efficiency.

As indicated by Blunt and Schmeling (1968) colored illumination is generally inadvisable for illuminating flares because of its relatively low luminous efficiency per unit weight or volume of source. Its special applications are for increasing the contrast between a particular target and its background, or as a distinctive ground target marker. Color purity is affected by several variables. Data on color purity as a function of several variables are contained in an article by Douda (1964). Green is normally desaturated by yellow and/or red; and blue, in addition to being contaminated by mixtures of red, is hard to produce at an acceptable intensity level.

For a detailed listing of spectral illumination characteristics and composition codes for hundreds of indexed pyrotechnic compositions of white, yellow, red, green and blue flares, the reader is referred to tables XIV–XXI compiled by Blunt and Schmeling (1968).

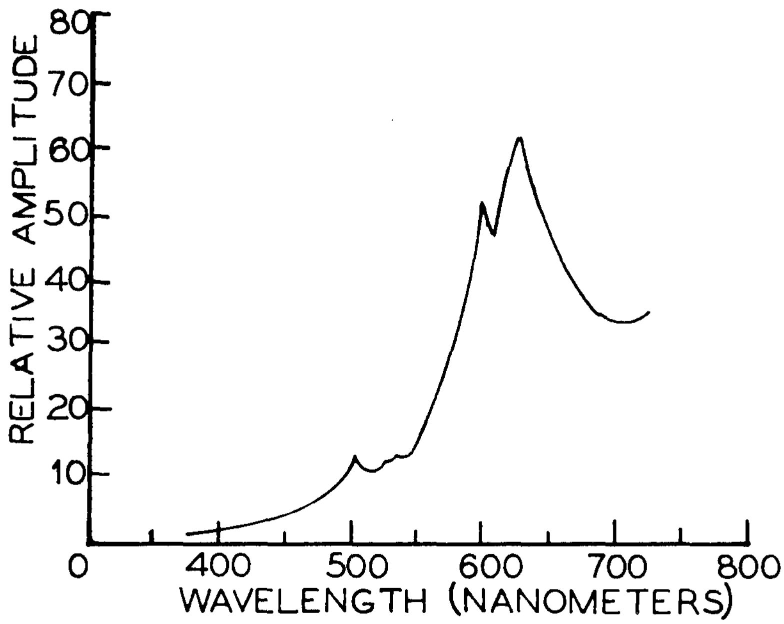

Figure 7. Wavelength Spectrum of a Typical Magnesium Flare

Within recent years a considerable amount of applied pyrotechnic research has been reported which deals with the physical/chemical reactions in the plume of the burning flare. Such studies attempt to demonstrate and explain causal relationships between the variables associated with these reactions and the luminous efficiency of the flare candle.

Some of these studies reported by Hamrick et al. (1968) have been based on math-modeling and empirical approaches utilizing photographic, spectroscopic, x-ray and radiometric analysis. The technology required here includes such specialized areas as fluid mechanics, thermodynamics, combustion, and spectroscopy. Much of this research has relevance to the improved design of flare compositions. In this connection, a summary of findings and recommendations associated with the following variables will be presented: (1) Particle Size, (2) Amount of Magnesium, (3) Altitude Effect, (4) Flare Diameter, (5) Flare Binder, and (6) Flare Smoke.

In the report by Hamrick et al. (1968), evaluations of these kinds of factors are made with respect to an ideal flare which converts all of its heat of reaction into visible light emissions. "Thus all factors that influence a given flare's performance and cause its amount of emitted light to be less than that of the ideal flare contribute to the inefficiency of the flare burning process."

Particle Size

The Army Materiel Command (1967) shows, for an illuminating composition, an inverse relationship for both burning rate and candlepower as a function of a particle size. Figure 8 taken from the AMC pamphlet shows these relationships.

Amount of Magnesium

Hamrick et al. (1968) report a drop in luminous efficiency for small (1.76 and 2.66 inches diameter) flares when the percentage magnesium is reduced below 62 percent. However, for larger flares (4.25 and 7.35 inches in diameter) there is an increase in luminous efficiency for a simular reduction in magnesium content. Of the four flares tested, the greatest overall luminous efficiency was shown for the one having a diameter of 4.25 inches. These data are shown graphically in figure 9. The efficiency is not only a function of the magnesium-to-sodium nitrate ratio but also a function of the binder type. The optimum magnesium-to-sodium nitrate ratio at one flare diameter may not be optimum at another diameter.

In another study by Hamrick et al. (1968), which used a scanning radiometer to analyze small flares of 1-inch diameter, luminous efficiency was shown to increase from 29,300 to 57,400 candle-seconds per gram as the percentage of magnesium increased from 45 to 68. Under these conditions burn-times were shown to decrease while plume areas increased. Note, however, that this particular effect may not be extrapolated to other diameters.

Altitude Effect

Douda in NAD Crane RDTR 205 (1972) and RDTR 206 (1972) demonstrates in detail the effect of altitude (pressure) on the intensity and spectral distribution of flare emission. With

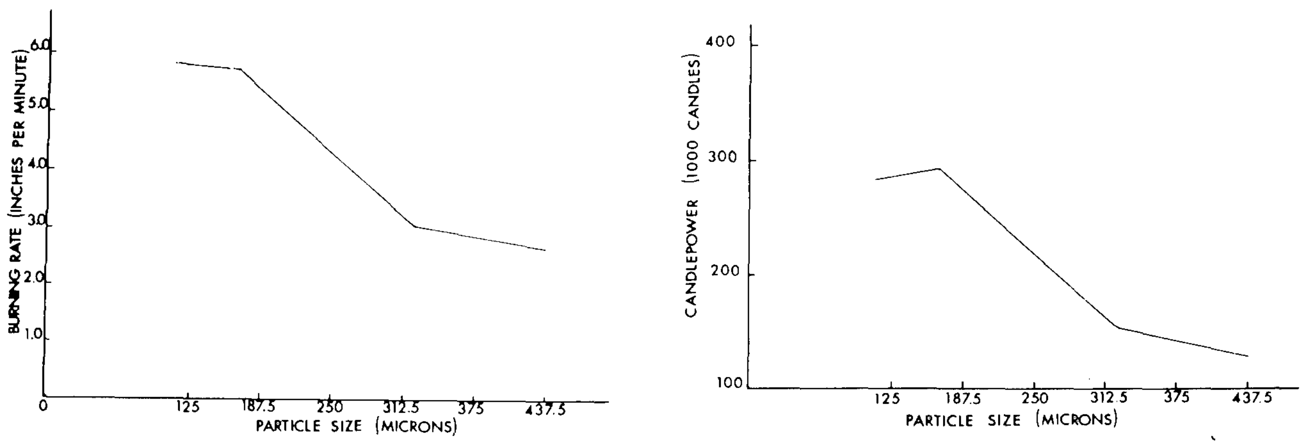

Figure 8. Effects of Magnesium Particle Size on Flare Burning Rate and Candlepower

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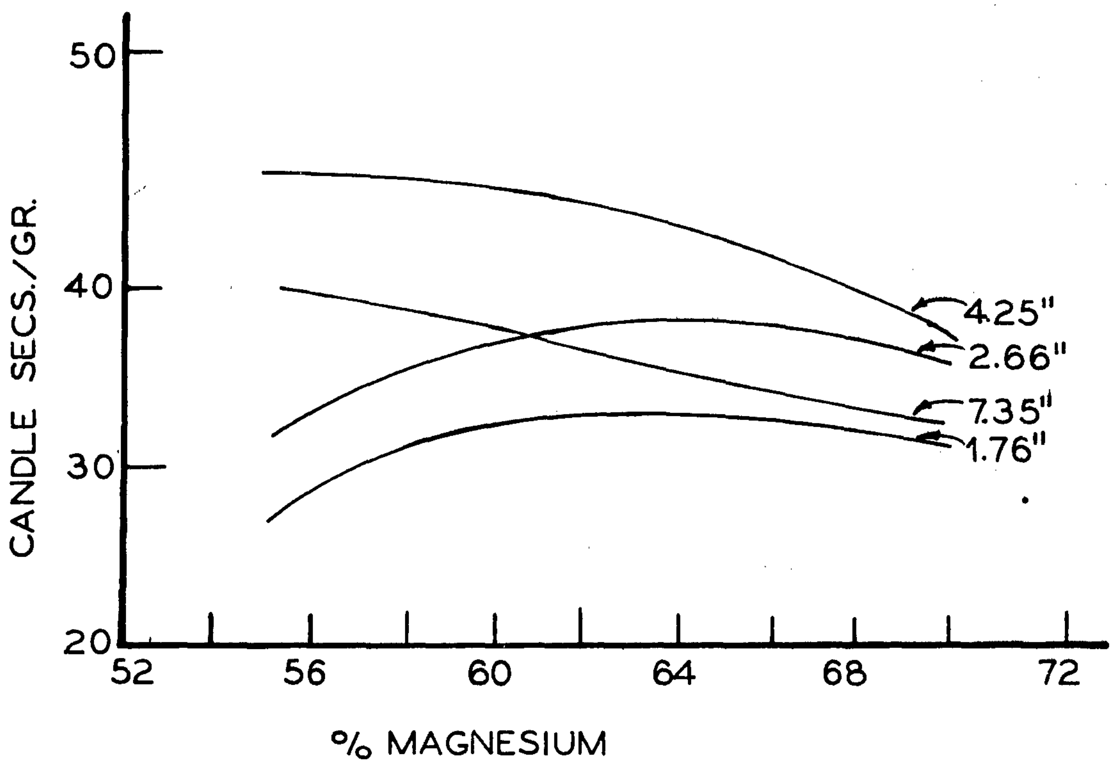

Figure 9. Luminous Efficiency for Four Flare Diameters as a Function of Percentage of Magnesium

increasing altitude, the illuminating flare intensity is greatly reduced by the reduction in its spectral continuum and in the broading of the sodium D lines.

Flare Diameter

Douda, (1968) has shown that the efficiency of a 30-percent magnesium pressed flare increases with up to 4.25 inches in flare diameter. Beyond this size, luminous efficiency rapidly decreases. In the case of cast flares, where plume size rather than flare diameter appears to be the critical factor, luminous efficiency levels off above a larger, 15-inch diameter. Binder levels necessary in making these large diameter cast flares introduce another variable into this diameter experiment making diameter efficiency statements very difficult. The Army Materiel Command (1967) discuss relationships of flare diameter and flare efficiency for colored flares.

Flare Binder

The flare binder used to consolidate the other flare ingredients is described by Hamrick (1968) as a low viscosity liquid which polymerizes upon the addition of chemicals that cross-link the binder molecules. A cast flare requires four times as much binder composition as a pressed flare. Binders containing fluorocarbons may be more effective because they are oxidizers. Since the luminous effectiveness of a flare has been found by Hamrick et al. (1968) to decline rapidly with increases in binder content, an optimum percentage of binder needs to be determined for each flare composition. That is one that will hold the composition without degrading flare performance. Tanner (1972) has investigated the effect of binder oxygen content on adiabatic flame temperature. The most important binder variable found was the relative amount of fuel and oxidizer elements in the binder compound.

Flare Smoke

According to Johnson (1966), two types of smoke have been identified for the magnesium flare. The first type, known as cenospheric smoke, forms the ash or fallout of a burning particle of magnesium and has no demonstrable effect on luminous efficiency. It is the second type, described as aerosol smoke, that can significantly attenuate the light output. For a downward burning flare of 8 inches diameter with 68 percent magnesium, aerosol smoke is typically buoyant and will rise with minimum interference, while, in the case of 59 percent magnesium composition, the aerosol smoke tends to hover below the flare and obscure its effectiveness. This effect occurs primarily in the last portion of the burn.

FLARE DEPLOYMENT FACTORS

Given a highly efficient candle for its source, any illuminating flare system must be designed in all of its phases of deployment, (launch, ignition, suspension, descent, and burn-out) so that the circle of light on the ground has the required brightness, area, stability and duration to permit required types and levels of target acquisition to occur.

Therefore, a logical starting point for discussion in this section of the report will be the ground illumination requirements for flares. Relevant data on the following topics will then be re-

viewed: altitude, burn-rate, rate of descent, flicker, candle orientation, multiple launch and flare shielding.

Ground Illumination Requirements

a. Intensity. Since the effectiveness of ground luminance is so dependent on the spectral reflective properties of targets and their background, the attenuating effects of atmosphere, observer viewing distance, physiological state of the eye, type of observer task to be performed, etc., it becomes meaningless to specify any single footcandle value that would be recommended for all flares. Much work needs to be done within a systems context to determine specific ground illumination requirements for a complete family of flare target acquisition tasks. Present illumination standards are somewhat arbitrary and are anchored to such ground illumination values as reported by Blunt and Schmeling (1968).

	Footcandles
Full Sunlight	10,000
Twilight	0.3
Full Moonlight	0.1

A criteria value of 0.2 FC has been used as a threshold for the sensors on the Pyrotechnic Evaluation Range at Yuma Proving Grounds.

Current operational parachute flare systems have different source intensities. These have been listed by the Joint Technical Coordinating Group for Air Launched Non-Nuclear Ordinance (JTCG/ALNNO) in the first row of table 1.

Using a terrain model approach, Hilgendorf (1969) has simulated flare drops of two of these systems (MK24 and Briteye) over 1:1000 scale model and shown significant target acquisition advantages (measured in terms of observer accuracy and response speeds) for the brighter MLU–32 system. Despite this apparent advantage, an upper limit of optimal flare intensity may have been exceeded in the Briteye since observers complained of excessive glare from the simulated five million candlepower source.

b. Color. No studies on this factor have been reported for illumination flare systems. As previously indicated, candles producing color are less efficient than standard illumination flares. Nevertheless, in certain cases, advantages may accrue to the deployment of colored flares which have spectra-zonal illuminating characteristics designed to enhance visible contrast for particular target/background combinations.

c. Area. Increasing the area of effective light on the ground may be dictated either by military requirements for wider combat zone coverage or by the observer's need for contextual cues to support his identifications. Research aimed at both these requirements is needed which shows relationships between extents of lighted areas and target acquisition measures.

d. Stability. Flares, not only produce noticeable flicker as they burn, but also cast moving shadows on the ground as they oscillate and drift with the wind. Again, we have little data to indicate the degree to which target acquisition is affected by these kinds of temporal/

TABLE I

PRINCIPAL FLARE CHARACTERISTICS

Characteristics	XM170	M8A1	LUU-2/B	MK45	MK24	ATTACK (1)	MLU-32	XM170E-1*
Candlepower (10^6) (2)	1.27	0.47	87	1.65	1.49	4.10	4.70	1.80
Burning Time (sec) (2)	137	236	286	202	187	303	324	1.35
Descent Rate (fps) (2)	7.61	8.37	7.72	7.47	6.45	9.03	6.41 (3)	8.50
Complete Round Weight (lbs)	12.0	17.6	29.5	28.0	26.5	103.6	155.0	15.0
Size-Diameter (in)	2.75	4.25	5.0	5.0	5.0	8.0	8.0	2.75
Size-Length (in)	36.0	25.0	36.0	36.0	36.0	61.5	63.0	44.0
Shipping Weight (lbs)	14.7	29.3	31.7	29.7	29.1	170.0	233.0	15.3
Shipping Volume (ft^3)	0.66	0.60	1.38	1.38	1.38	7.62	7.62	.825
Composition Weight (lbs)	8.0	10.0	20.5	16.9	15.6	61.7	90.1	10.0
User Service	Army	AF/Army	AF	Army/Navy	AF/Army/Navy	AF	AF/Navy	Army
Status	Development	Production	Production	Production	Production	Adv. Delop.	Devel.	Devel.

(1) Unverified, supplied by AF from AFATL-TR-70-71 & ADTC-TR-71-91.

(2) Based upon YPG PER Site data as received from Dec 70 test. Also, applies to a 0.2 ft-cdl illuminated level, flare burn thru optimum altitude and no wind condition.

(3) Unverified, supplied by AF from APGC-TR-68-81.

* XM170E-1 is the current replacement for the XM170.

spatial changes in light patterns. Until such determinations are made, one can hardly justify the cost of redesigning flares to eliminate flicker and drift.

One study soon to be published by Tyroler and Davis employs the terrain model (scaled at 160:1) located at Picatinny Arsenal. Here they have examined the effect of flicker on target recognition. This work measures target recognition illumination requirements at selected frequencies from 1 to 25 Hz and also non-flicker conditions. Initial results of this experiment indicate that the lower frequencies approximately 3–10 Hz require more illumination for target recognition than do the higher frequencies of approximately 12–25 Hz. The higher frequencies differ little from the no flicker conditions in the illumination required for target recognition.

e. Duration. Like area, time is a factor in flare illumination, and is, in turn, dependent on both operational and observer requirements. Over-extended exposure may be tactically disadvantageous (unnecessarily warning the enemy or revealing friendly forces on the ground), while too brief an interval of light may not afford the observer enough search-time to carry out his assigned task. This problem of exposure duration arises in connection with the design, suggested by Tyroler (1971), of rapid burning flares which emit brighter light for shorter periods of time. Research is needed to determine best intensity/time tradeoffs for flare-light to enable an observer to perform effectively in tactical situations.

Flare Altitude

A basic point of departure in planning a flare launch cycle is consideration of the altitude range over which the flare is effective. In particular a single altitude exists (and can be determined) for any flare where a maximum area can be illuminated to a predetermined level. This so-called "optimal height" of a burning flare can be derived from basic illumination theory and, in the simplest case, is based on the following assumptions:

a. That the flare represents a point source of illumination having known candlepower (I) and altitude (h).

b. That the ground is essentially a plane surface, either normal to the path of light from the flare, or at some known angular inclination from it.

c. That the wind velocity is zero and light transmission through the atmosphere is 100 percent.

Given the above assumptions, along with specific values representing flare intensity and ground illumination requirements, Cohen and Kottler (1954) have applied the inverse square law of light ($E = \frac{I}{D^2}$) to calculate:

(1) The optimum height (h opt) of the flare for a desired radius (Ro) to be illuminated at a specified level of footcandles (E):

$$h\ opt = 0.71\ Ro$$

If an average ground inclination of 45 degrees is assumed, the equation becomes:

$$h\ opt = 0.28\ Ro$$

(2) The required minimum flare candlepower (I) for a desired radius (Ro) with the desired footcandles (E) at the periphery.

$$I = 2.58 \; E \; Ro^2$$

For an average ground inclination of 45 degrees the equation becomes:

$$I = 1.24 \; E \; Ro^2$$

(3) The optimum height of a flare (h opt) which will provide a specified illumination (E) in FC on the ground with a specified candlepower (I):

$$h \text{ opt} = 0.438 \; I/E$$

To better portray the concept of "optimum height," Laswell (1963) has developed a family of curves (shown in figure 10) in which flare intensities are varied from $.5 \times 10^6$ candlepower to 3.5×10^6 candlepower and the threshold illumination values are held constant at 0.20 FC (a value which has been arbitrarily selected based on its usage for protective lighting of large areas). Figure 11 shows the optimum flare heights required to obtain maximum area at this illumination value for different flare intensities. For maximum areas pertaining to any other required illumination value, different sets of "optimum altitudes could be similarly derived.

As previously indicated, the Pyrotechnic Evaluation Range (PER) at Yuma Proving Grounds offers a sophisticated technique for continuously recording ground illumination patterns under the falling flare. It will be recalled that the PER technique uses an array of sensors covering a field 8,100 ft square. In tests reported by Brooks (1970) of illuminationg cartridges (M335A1) fired to function at a 700-meter height, the sensors were set to respond to 0.05 FC of illumination. The curve shown in figure 12 is derived from the PER measuring technique and shows how the effectively illuminated ground area (derived from a continuous record of number of sensors lit) actually varies with height throughout the functional period of the flare. A phenomenon referred to as the "search light effect" was observed in these tests. This phenomenon is attributed to the fact that light from some flares approximates a directed beam whose axis is oblique to the surface. The resulting elliptical pattern rotates about one of its foci resulting in several areas being intermittently illuminated. This effect is noticeable and could prove troublesome to the observer in target acquisition.

Using his 1000:1 scale terrain model, Hilgendorf (Aug 1971) measured target acquisition responses at three simulated ignition altitudes (2000, 2500, and 3000 ft) for a simulated MK24 system. The greatest number of targets were acquired at the lowest (2000 ft) ignition altitude.

Considerable use has been made of the equations listed above for "optimum heights" of flares to provide a maximum area lit to a selected level of illumination. However, the use of such data for target acquisition disregards many critical factors which need consideration and/or empirical determination. These include the spatial relationships between flare, observer, and target, visual task to be performed, mission requirements, etc. Note also that when "optimum height" determinations are made, the first one-third to one-half of the burn period occurring above the "optimum height" may not provide adequate illumination for target acquisition, yet give advance warning to hostile forces. This inadequacy has been pointed out in the Army Field Manual FM 20–60 (Jan 1970).

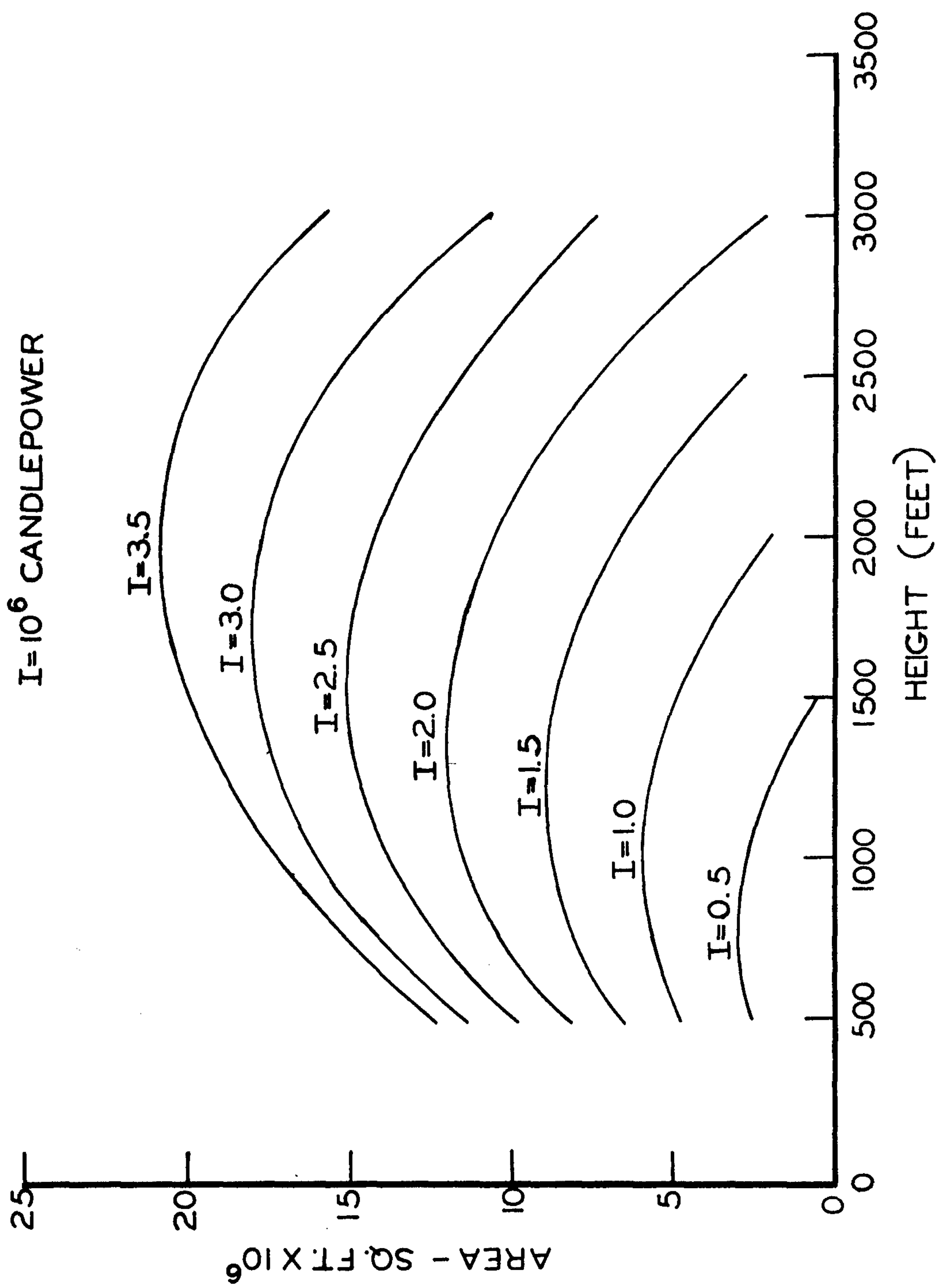

Figure 10. Ground Area Illuminated to 0.2 Footcandles by Flares at Various Heights and Intensities

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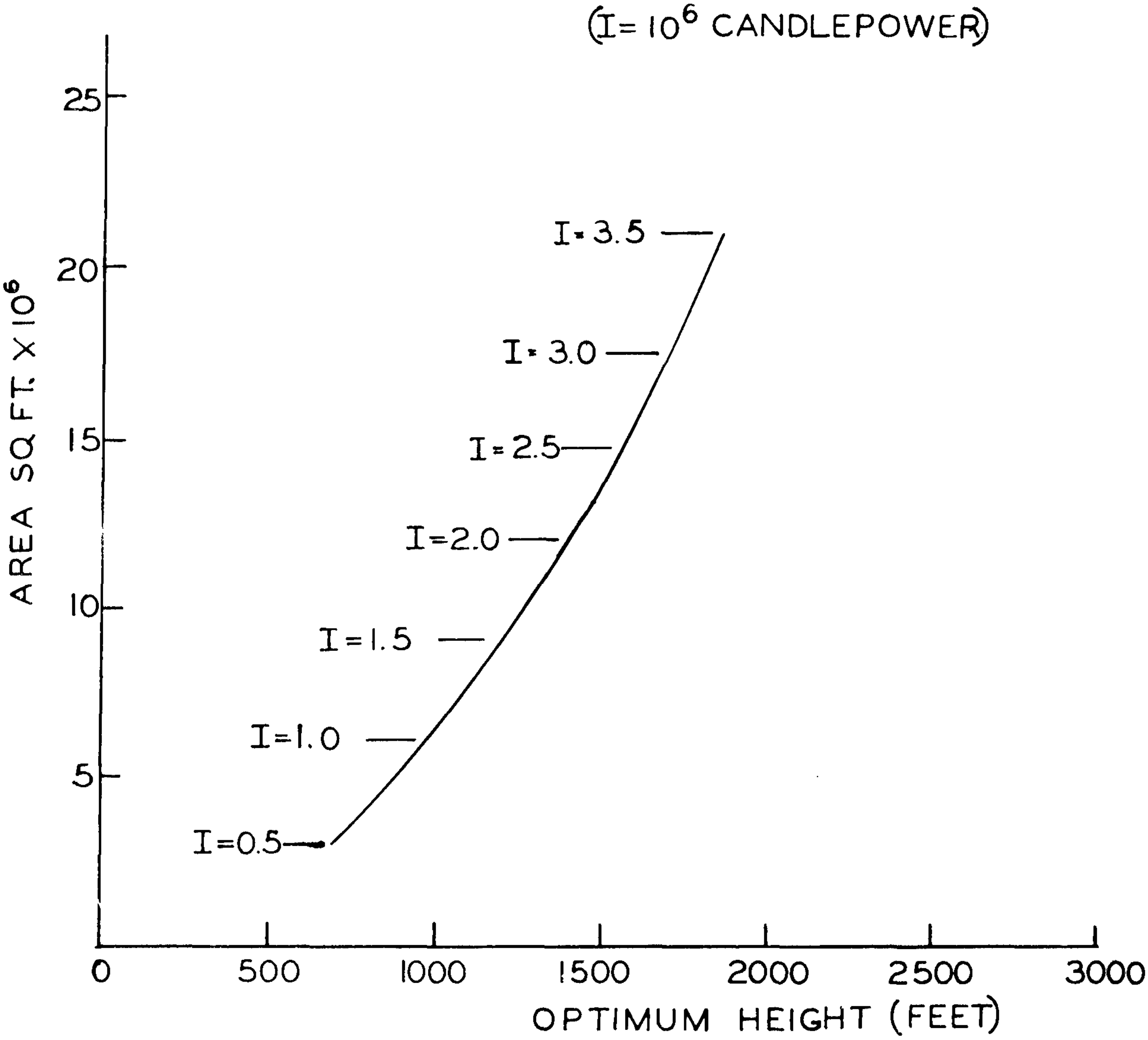

Figure 11. Ground Area Illuminated to 0.2 Footcandles at Optimum Heights of Flares with Different Intensities

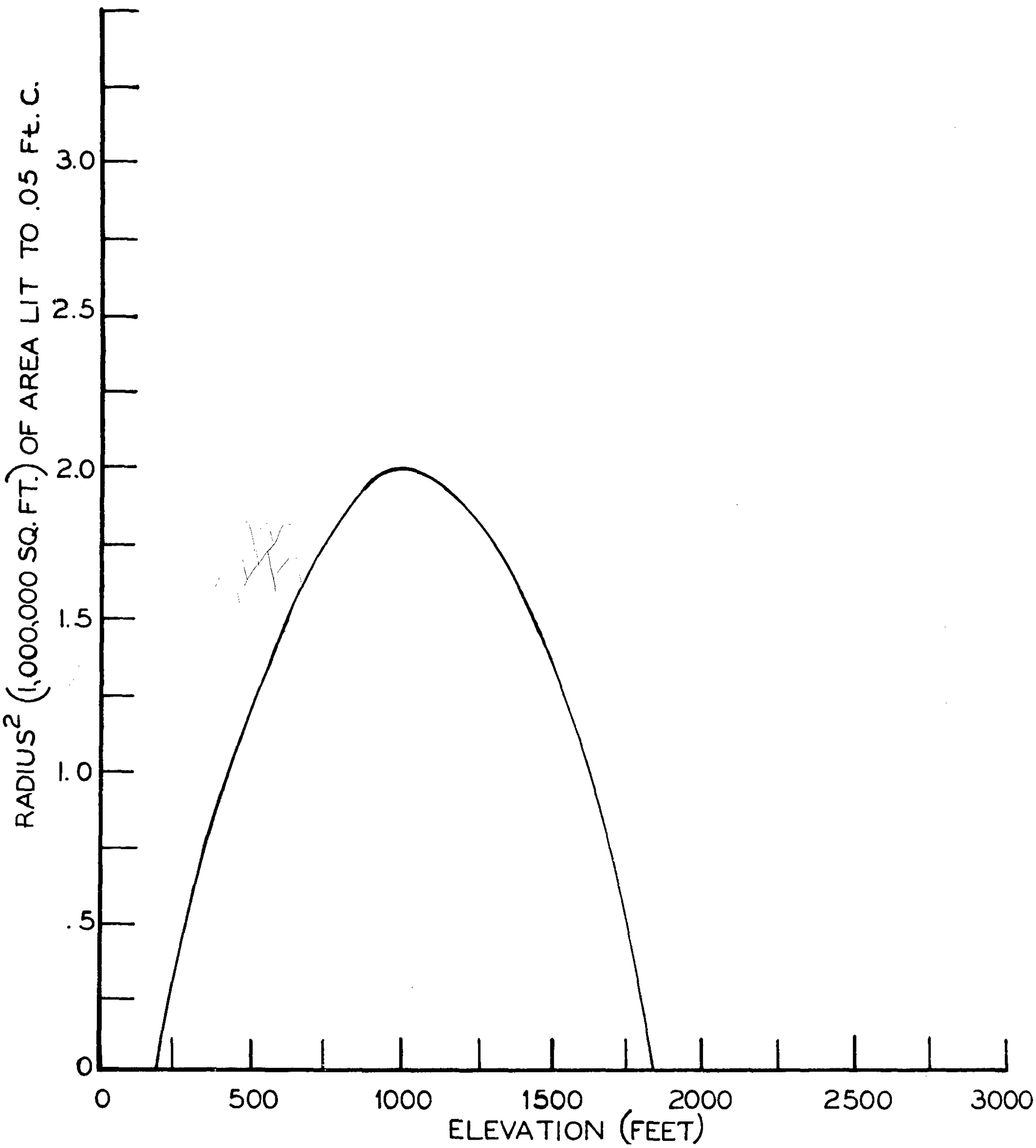

Figure 12. Radial Measures of Ground Illumination from the Pyrotechnic Evaluation Range for the M335AI at Various Elevations

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Burn-Rate

Associated with the composition of the flare is the rate at which it burns. Moreover, there is a reciprocal relationship between burn-time and intensity, i.e., halving the burn-time approximately doubles the intensity of a flare. Tyroler, in an unpublished article (1971), is concerned with four contingencies related to burn-time which are clearly important in any estimate of flare system effectiveness:

a. The amount of area adequately illuminated.

b. The total time during which the area is so illuminated.

c. The alerting of enemy personnel in the target area prior to adequate illumination.

d. The probability of the illuminated area remaining in the desired location.

Given all these considerations Tyroler suggests that the design of a new flare of equal size but faster burn-time, might increase effectiveness; moreover, he feels that such a design might best be achieved by the incorporation of successive stages of decreasing burn-time (incremental concept). Such a modification could provide a larger ground area of adequate illumination and maintain this illumination during the early period of flare ignition. The likelihood of prematurely warning an enemy would also be diminished and the probability of prevailing winds blowing the flare off-target prior to the establishment of adequate illumination would be decreased.

Rate of Descent

Another factor controlling the effectiveness of a flare is its rate of descent. Other things being equal, the most effective use of a flare would be to hold it stationary at the optimum altitude over the target during the entire burn-period. Barring the feasibility of this condition, the next best recommendation is to slow the flare's descent-rate. However, this requires enlarging the size of the parachute, thus increasing both cost and weight of the total flare package. In fact, Laswell (1963) states that the cost of cutting the descent rate by one-half raises the total cost of flare deployment six times. In any case, an appreciable drop-rate of at least two to three feet per second (FPS) is required to remove light-attenuating smoke from the flare. Also, too slow a descent will increase susceptibility to wind drift. Average drop-rates for current operational systems evaluated by JTCG/ALNNO (1971) vary from 6.4 FPS for the MK24 to 8.5 FPS for the M8A. One should also note that these rates are not constant throughout the descent period but decrease as the burning flare loses mass and generates heat.

Flare Orientation

Flare illumination can also be affected by the orientation of the burning candle, i.e., whether it is suspended in its typical face-down position, or whether its orientation is altered so that it descends in either a horizontal or a face-up position. In a tunnel test Feagans (1967) compared the intensities of multiple flares burned side-by-side either in a perpendicular or parallel align-

ment with the plane of the detector. The first arrangement represented "burning across a front" and resulted in a four-fold increase in candle power for four flares oriented in this position. The second arrangement represents "burning in depth" and resulted in no appreciable increase in intensity with increments up to four flares. In an expansion of this kind of research, Wildridge (1966) checked out various single or multiple flare systems capable of producing five million candle power for a 5-minute burn-time. Both static tests from tower facilities and flight tests were run. Two basic orientations were studied; multiple candles burning face downward and multiple candles burning horizontally. The horizontal method of suspension was found in general to provide illumination equivalent to the vertical system and had the following specific advantages: (1) the possibility of cleaner smoke removal, (2) more uniform illumination patterns, and (3) elimination of heat arising around the candle (which could burn parachute suspension cables). The main disadvantage here was the increased cost and pay-load requirement for a spreader mechanism to suspend the flares in a horizontal position.

Multiple Flare Systems

Conventional single flare systems are so limited with respect to the intensity, area, and duration of the ground illumination they can provide that many military applications require the use of multiple flare systems. One type of multiple deployment would be to release several flares simultaneously, these either being suspended from a single parachute system or from individual chutes. Aside from payload cost, two or more flares dropping from a single chute can cause problems such as over-rapid rates of descent or excessive oscillation. If the heat and smoke of a heavy flare system could be effectively utilized, the rates of descent might, however, be decreased to tolerable limits.

With simultaneous multiple-chute deployment Wildridge (1966) states that mutual interference is likely to occur. The smoke of faster-falling flares may attenuate the light of a slower one, or the candle of one flare may burn the shroud lines of another. Wildridge also refers to another malfunction of multi-chute systems known as "squidding" whereby the system reaches a velocity below the opening velocity of one of the parachutes causing it to dump.

An alternative kind of multiple-flare drop involves successive discrete deployments with appreciable intervals between drops. Although this sequential launching avoids the payload and interference problems of simultaneous launch, it does introduce spatial separation of light patterns which would have been mutually reinforcing had they come from a single source. However, according to Blunt and Schmeling (1968) loss of ground illumination due to this separation will not be too severe if the distance between units in a train of flares and the center of their mass does not exceed ten percent of the source height. This provision can be met even at low altitudes and high speeds with the SUU–12 system which can maintain launch intervals down to 0.10 seconds.

If the main concern, however, is lighting up an extensive area rather than approximating a single source, then much larger inter-flare distances can be used. If the area is to be a long narrow path, Blunt and Schmeling (1968) offer a formula for computing the ground illuminance in foot-candles of a point beneath a numbered string of flares of known height, candle

power, and separation. Using their mode of analysis the illuminance of a point (Ep) in the center of a seven-flare string is shown to be 4.12 I/h2 (where I = candle power and h = altitude). This formula reveals a principle of diminishing returns whereby increasing the flare number by 30 percent (from 7 to 9) would only increase the brightness coefficient by 7.5 percent (from 4.12 to 4.42).

Another formula is given by Blunt and Schmeling (1968) for the case of a circular launch-path around which flares are being deployed at regular intervals. Here, the illumination at a point on the ground (E_p) below the center of the circular path will depend on the number (n) intensity (I) and altitude (h) of the sources as well as the circumference of the flight circle with radius (a). The formula reads:

$$E_P = \frac{n\,I\,H}{(h^2 + a^2)^{3/2}}$$

Laswell (1963) has developed a formula stating that the maximum area (A max) illuminated to a specified level with a given intensity flare will be directly proportional to the product of the flare intensity and its optimum illuminating height.

$$A\ max = K\,I\,h_{opt}$$

Based on this expression he states that two flares with half the intensity of one large flare would illuminate somewhat more than twice its area if they were positioned in such a manner that overlapping reinforcement in the respective illumination patterns is obtained. However, this type of gain is relatively small (about five percent of the maximum area) and may not be cost-effective.

Starrett (1964) provides a series of analytical and numerical formulae for determining the Ground Illumination Contour (GIC) which results from linear deployment of an arbitrary number of flares (with equal separation and at the same height and intensity). Geometric coordinates (X,Y) for a GIC at any specified value of illumination is calculable from the following equations derived by Starrett:

$$E = hI \sum_{j=1}^{N} (h^2 + R^2{}_{jP})^{-3/2}$$

where $R^2_{jP} = [X + (N - 2j + 1)\, d/2]^2 + Y^2$.

for $j = 1,2 \ldots N$

E = Illumination required on the ground in footcandles

h = Flare height

I = Flare intensity in candles

R_{jP} = Distance (feet) from the ground point directly below flare j to the ground point P in feet.

N = Number of flares

d = Distance between flares (feet)

X,Y = Respective coordinates of the GIC

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A value of Y is sought which will satisfy the above equations when X is fixed and N, d, E, I and h are given.

Starrett also provides a machine program (GRILCO) written in FORTRAN for the IBM 709 for generating GIC graphs, printed listings of their coordinates or other information necessary to produce them. A machine-plotted output for a ground illumination contour of 0.5 foot candles resulting from a string of five flares is shown in Figure 13.

Hilgendorf (Aug 1971), using his 1:1000 scale terrain model and simulated launch trains of MK24 flares, tested four separation patterns at simulated altitudes of 2.0 and 2.5 thousand feet. These were: (1) six flares, 0.25 miles apart; (2) six flares, 0.50 miles apart; (3) four flares, 0.75 miles apart; and (4) two flares, 1.0 miles apart. In each case an observer was required to locate two types of targets. The results showed no improvement in target acquisition with increases in numbers of flares or with decreases in their separations. This rather unexpected finding was at least partially accounted for by the increased glare effects of the longer more-continuous flare train which caused a sufficient number of targets to be missed on the far side of the flare to offset the benefits of higher terrain illumination.

Flare Shielding

A recent innovation in flare technology reported by Carlson and Jewsbury (1968) (1969) has been the addition of a thin, conical metallic shield. This is illustrated in Figure 14 and has been designed to provide the following advantages:

a. Concentration of light below the flare where it is needed.

b. Reduction of light above the flare where it could expose friendly aircraft or provide a disturbing glare source to a pilot or observer.

c. Allowing light-occluding smoke to escape through the top (chimney) of the shield, thus further improving the ground illumination while providing an overhead screen for friendly aircraft.

One of the problems posed by Carlson and Jewsbury in designing an effective shield was how to prevent oscillation of both candle and shield during descent. This would not only cause a disturbing flicker but might also induce the illusion that stationary ground targets were moving. Shields having 60-degree included angles and varying in length from 36–54 inches were found to have sufficient stability to effectively control oscillation in the MK24 shielded system.

Maximum smoke evaluation was also established for this system by means of a 54-inch vertical shield height and a 2.4 sq ft top exit area. In comparison with the naked flare this shield was shown to reduce glare and smoke above the candle while increasing ground illumination below. Descent of the heavier payload was slowed down to the required rate by using a larger (28-ft diameter) parachute.

The above described system was evaluated by Bradley (1969) using a visibility model which

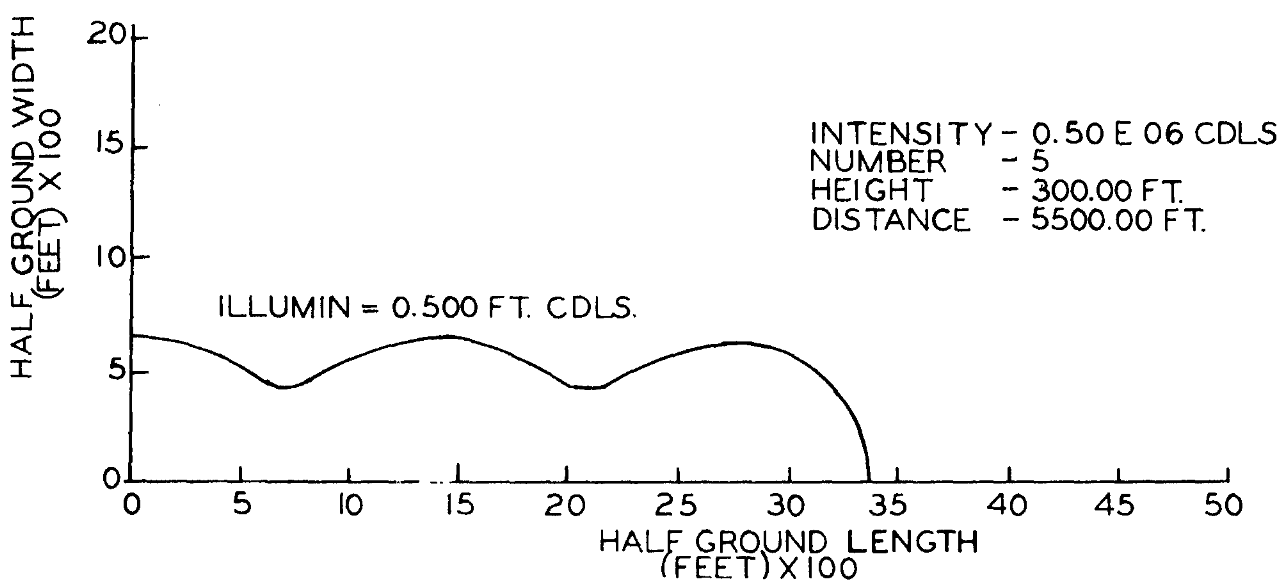

Figure 13. Machine Plotted Output for a Ground Illumination Contour of 0.5 Footcandles

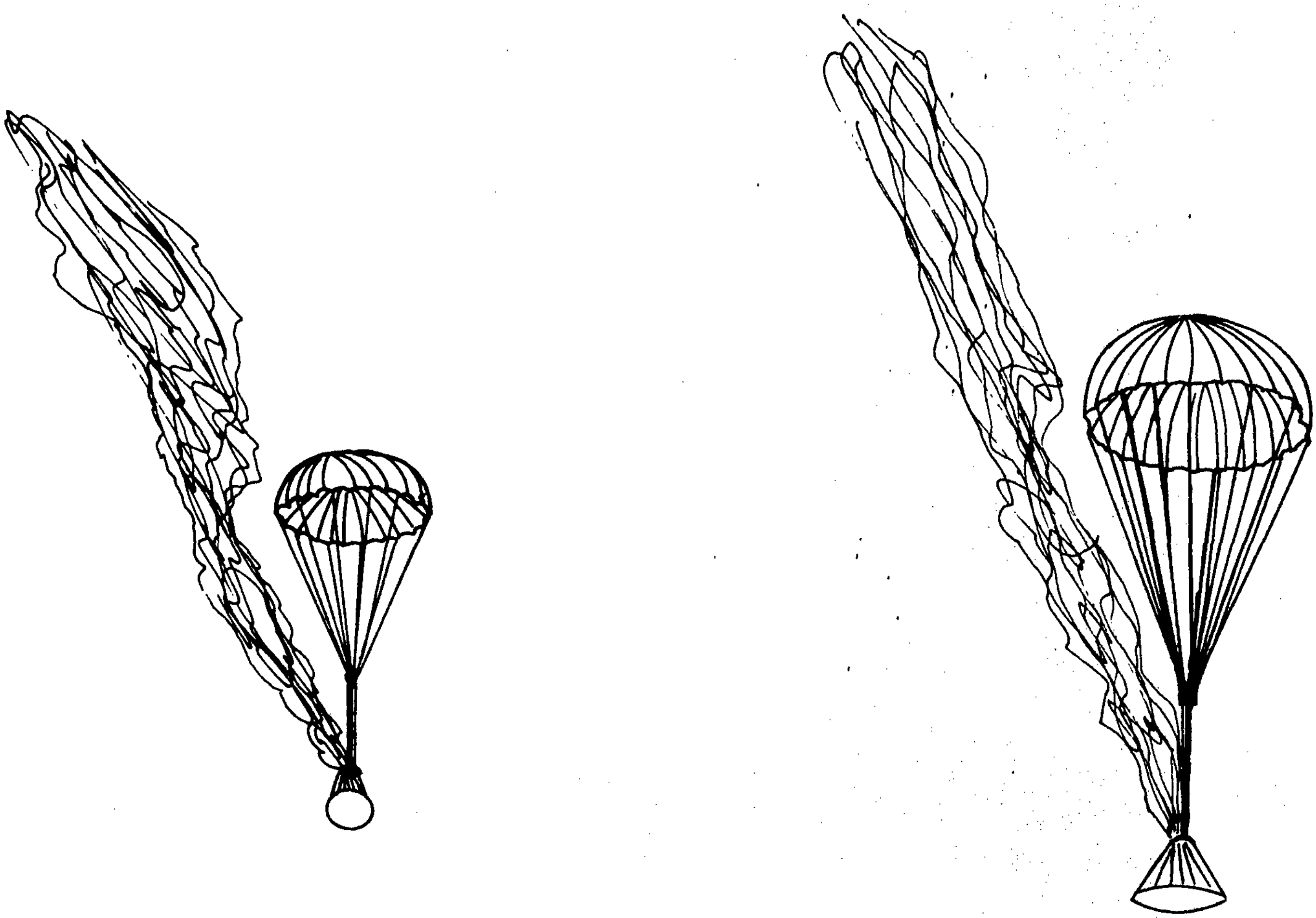

Figure 14. A Shielded Flare at the Beginning and End of the Burn Period

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incorporated the following variables: (1) Target/background reflectivity; (2) Attenuation of light from the flare to the target, and from the target to the observer; (3) visual angular subtense of the target; (4) Path luminance to the observer; and (5) flare glare. Series of computer runs were programmed for shielded and unshielded flares at altitudes of 2600 and 1500 ft. As shown in figure 15, the results indicate that glare effects (and the advantage of shielding) increase when the angle formed between the flare, observer and target is small.

Jewsbury (1968) has measured the luminous intensity of both shielded and unshielded flares in terms of the number of degrees from the center of their respective illumination patterns. These data are graphically portrayed in Figure 16. It can be seen that, for angles of less than 40 degrees, shielded flares provide greater brightness. However, for angles greater than this value (i.e., further out from the center of illumination), unshielded flares give stronger light.

Hilgendorf (Apr 1971), again using his terrain model and simulation facility, compared the performance of observers searching for tactical targets under conditions of both shielded and unshielded flare light. Shields were effectively simulated by modified flashlight reflectors coated with opaque white paint. Terrain illumination for each type of flare approximated the patterns shown in Figure 16. The results, however, did not support the efficacy of flare shielding for target acquisition since no significant advantages for this condition could be demonstrated with respect to number of targets found, number of errors, or observer response time. It was pointed out that the results could have been affected by the nature of the acquisition task (wide area search for targets of opportunity) and that other potential advantages of shielding (e.g., providing obscuration of overhead aircraft) were not evaluated by this test. Nevertheless, recent field testing by the Armament Development and Test Center (Ernst, 1972) has validated Hilgendorf's finding in showing no improvement in target acquisition using the shielded flare.

WIND DRIFT

Most of the previous discussion has been based on the assumption that a flare drops perpendicularly from its launch point to the earth's surface. Mission planning for target acquisition under flare light would be greatly simplified if this were the case. However, winds of 5 to 20 miles per hour are usually prevalent in the flare's environment and can easily cause the pattern of light to drift away from the intended target area. For a typical 3-minute flare one might expect movements of more than a mile. Tyroler (1971) points out that because winds are usually gusty the flight pattern of a flare may well become unpredictable even if the average wind velocity is known, and that "the longer a flare burns the less likely it will be usefully placed for its entire burning time."

Nevertheless, a mathematical approach for achieving effective flare utilization with nominal wind velocities by computing two circles of adequate ground illuminations (based on the inverse square principle and assumed to be 0.2 FC has been proposed. A smaller circle represents the situation for the higher ignition altitude and a larger circle for the lower, burn-out altitude. With no wind drift a continuous succession of concentric circles can be constructed to represent adequate ground illumination during the burn-time of the flare and any target visible within the small circle at ignition would obviously remain visible until bu[illegible]

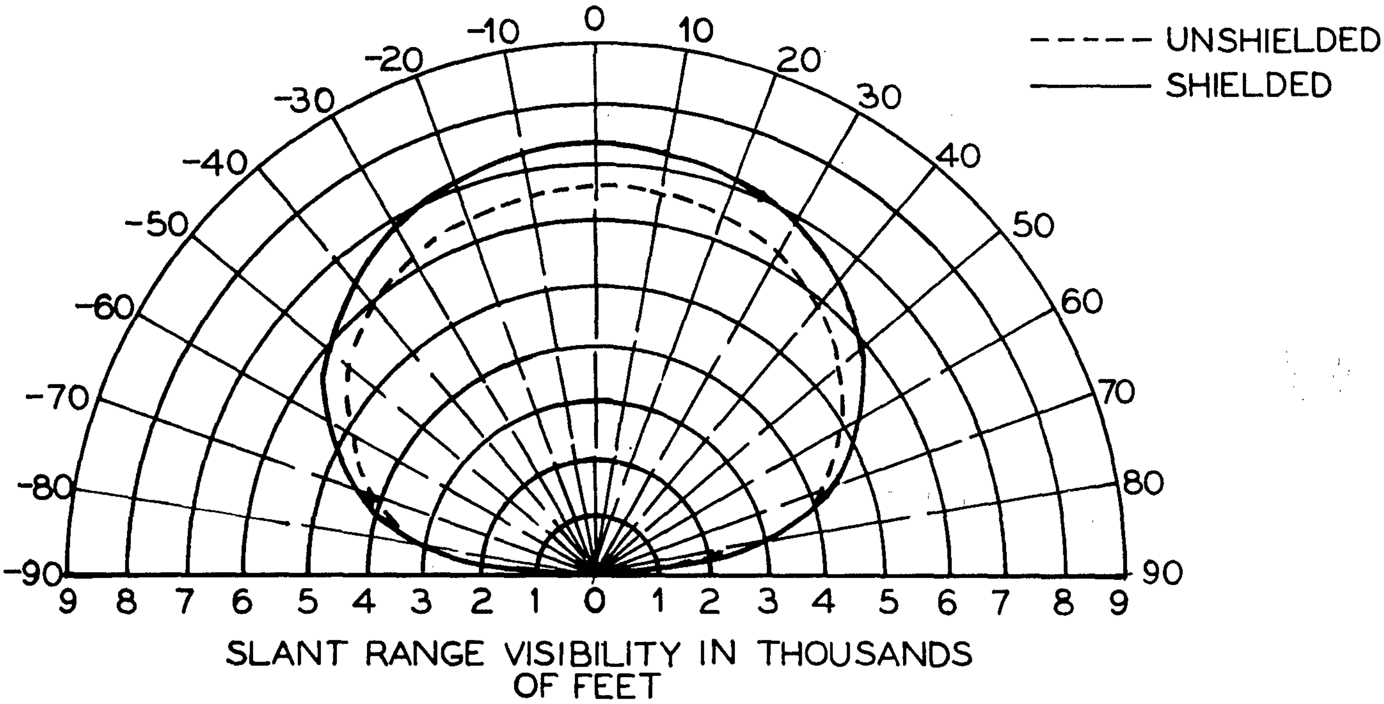

Figure 15. Visibility Plot for Shielded and Unshielded Flares at Different Flare-Observer-Target Angles

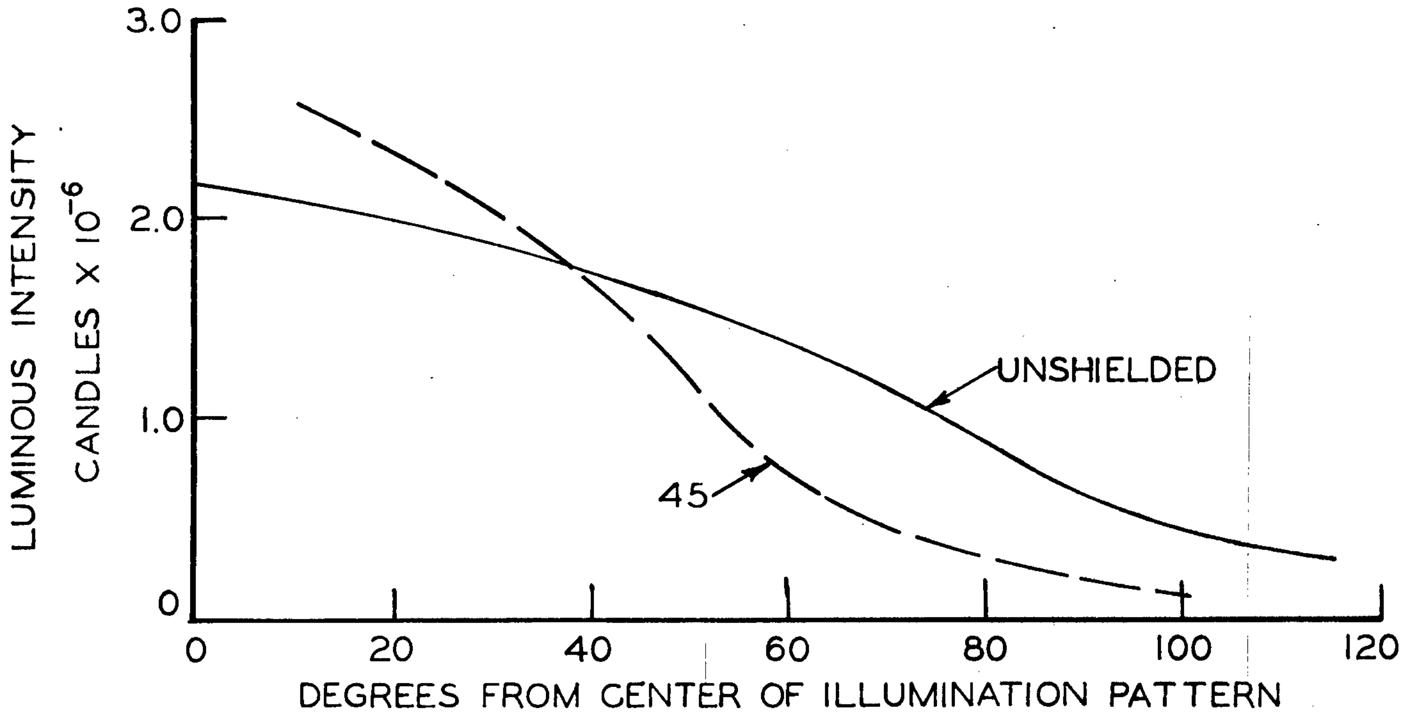

Figure 16. Luminous Intensity versus Degrees from Pattern Center for a 60-degree 45-inch Shield

however, causes the circles to drift apart in the direction of its movement, and, given sufficient velocity, can render initially perceived targets invisible. The planning principle here is to so select the type of flare (based on its ignition/burn-out altitudes, burn-time and candlepower) for a given wind velocity that: (1) there will be spatial overlap between the respective circles of visible light at ignition and burn-out; and (2) the target will remain in this overlapping area.

In accomplishing this set of circumstances, the planners goal would be to achieve ignition at an ideal altitude with the flare drifting directly over the target and burning out at an ideal altitude. Figure 17 provides a graphic portrayed of the tolerable wind drift distance for acquiring a target under one set of conditions.

ATMOSPHERIC EFFECTS

Just as there is almost always wind to complicate the planning of flare missions so there is an atmospheric medium which scatters and absorbs the light being transmitted from the flare to the ground, from the ground to the observer, and from the flare to the observer. Irradiation of light, as would be predicted by the inverse square law is thus reduced by a so-called extinction coefficient which is less than unity and depends upon such factors as wavelength, atmospheric gases, temperature, pressure, as well as amounts of rain, fog, snow, dust and other aerosols. Visibility or meterological range refers to the horizontal distance at which atmospheric attenuation (extinction) reduces the apparent contrast of a target to two percent of its intrinsic contrast.

On cloudy nights under flare light conditions target visibility is subject to two kinds of atmospheric degradation. One of these involves light reflected from the target and attenuated according to the extinction coecient. The other, referred to as path luminance, involves light which is scattered by the atmosphere and added to the attenuated path of light entering the observer's eye. The net effect of this combined attenuation and scattering is to further veil the visibility of the target against the background. These two atmospheric effects along the observer's line of sight are depicted in figure 18. Another visual path shown in the figure which represents still further degradation comes directly to the eye from the flare which acts as a glare source.

Lohkamp (1970) has constructed a mathematical model which predicts the probability of target detection under various conditions of atmospheric clarity, flare location and intensity, as well as pertinent characteristics of the target background. According to the author, this model utilizes the best available psychophysical and engineering data and is intended to accept improved data as this becomes available. Once its validity is checked and all necessary improvements are made, it can provide the designers, planners, and evaluators of flare systems with a sophisticated tool for predicting target acquisition, taking into account the effects of source, medium, target, background, detection and geometry as a function of time. More recently, Bradley and Lohkamp (1973) have analyzed the effect of atmosphere on target-background contrast under flare illumination. Their analysis of the reduction of target-to-background contrast attributable to atmospheric effects is described in figure 19. Figure 19 contains four curves, each of which represents a particular geometric flare-target-observer relationship. The specific relationships studied are given in the Bradley and Lohkamp report.

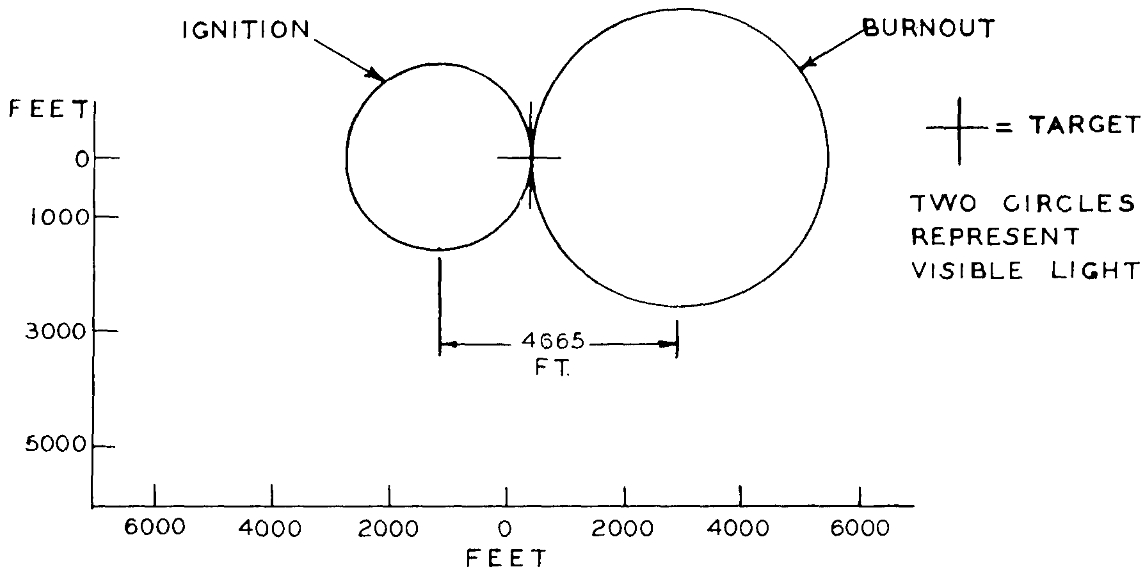

Figure 17. Tolerable Wind Drift for Target Acquisition
(See text for explanation)

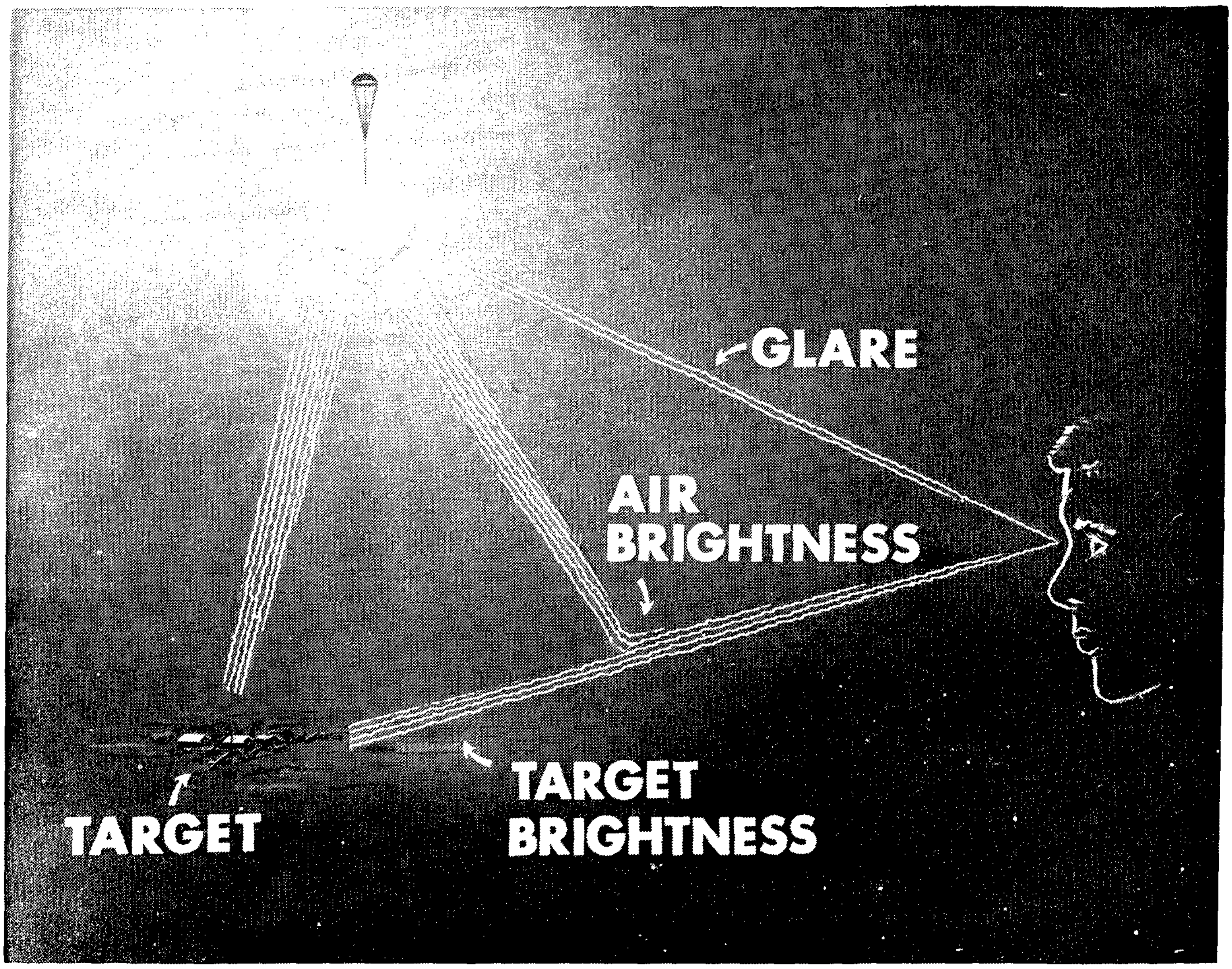

Figure 18. Paths of Atmospheric Degradation for Target Visibility under Flarelight

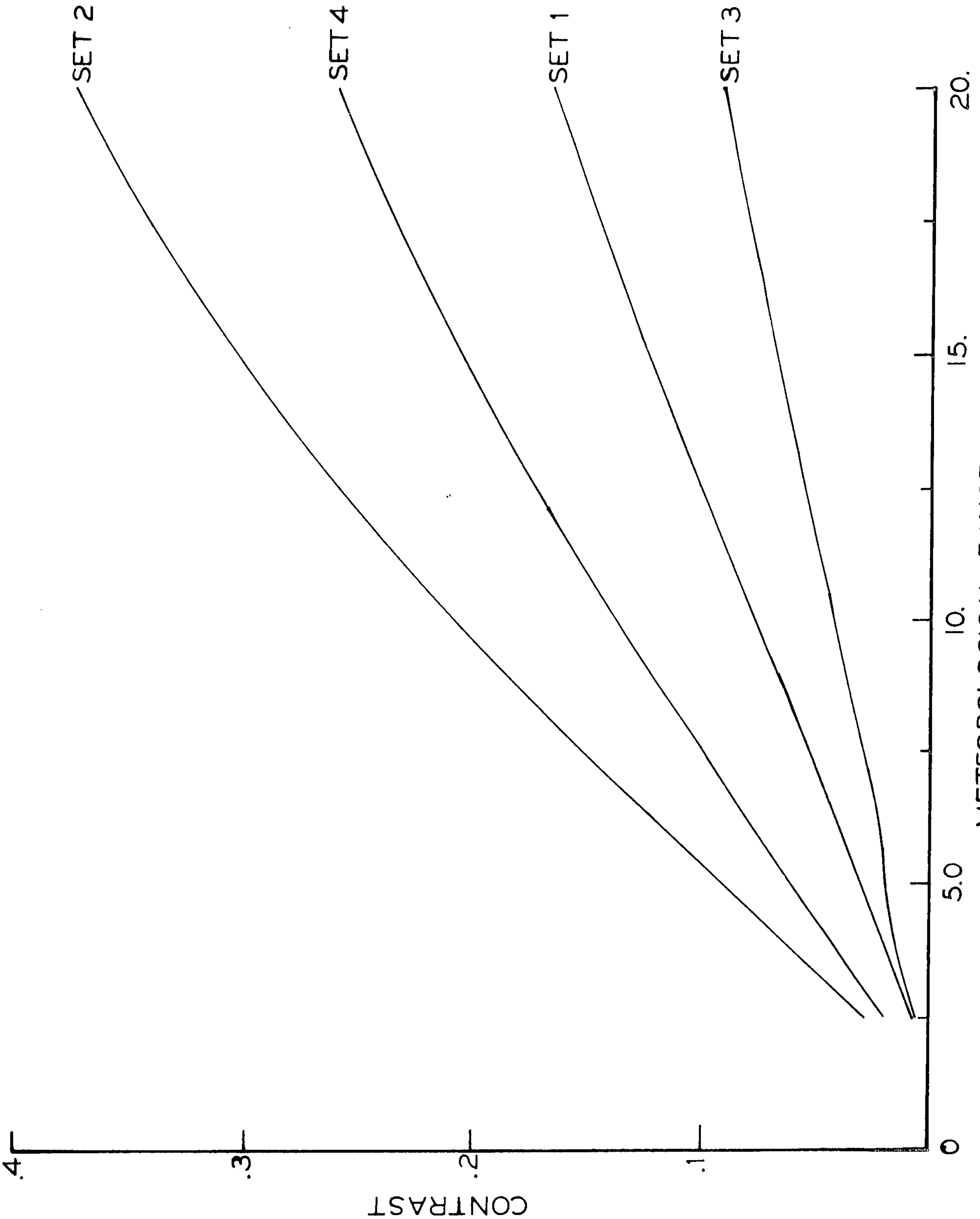

Figure 19. Effect of Atmosphere on Contrast under Flare Illumination

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Katz et al. (1970) has designed an environmental chamber for the study of visual acuity with simulated flare light under cloud conditions. An experimental generator was constructed to produce aerosol particles of stearic acid (having a diameter of 0.68 microns). These were dispersed into the room at one of two levels of density (25×10^5 or 5.0×10^5 particles/ml). Other experimental factors were two simulated flare light intensities (2×10^6 and 5×10^6 cp) and the use of yellow (haze cutting) eye filters. To measure visual acuity, subjects were required to select the smallest discernible break in a diminishing series of Landolt C's. Results indicated: (1) no advantage for the yellow filters, (2) loss of visual acuity at the lower flare intensity, (3) a linear decrease in visual acuity with increasing fog level. This study represents a beginning step in the simulation of a real-world environment (hitherto only studied in field tests) as a measurable experimental factor. Using the guidelines suggested by this study, the Aerospace Medical Research Laboratory has installed an experimental chamber with an associated aerosol generator and nephelometer for future visibility research.

TARGET/BACKGROUND FACTORS

There are obviously many measurable parameters associated with both the target to be acquired and its background which can affect the planning and outcome of a flare mission. For the target these include size, shape, color, brightness, and contrast. Additional background factors include brightness, color, texture, clutter elevation, etc. The impact of these variables on flare light acquisition will not be reviewed in this paper; however, readers are referred to Blunt and Schmeling (1968) and Clisham (1969) who have covered this subject matter. Blunt and Schmeling's paper provides a multi-step planner's guide for selecting an appropriate flare from known physical characteristics of the target being sought. These steps involve calculation of: (1) target reflection, (2) inherent target contrast, (3) target area, (4) observer-to-target viewing distance, (5) visual angular subtense of the target, (6) threshold of apparent contrast at the selected viewing range, (7) intensity of the required flare, and (8) range at which required ground illumination level may be produced from available flares.

Despite the inclusiveness and rigor of this computational model (which is based on a variety of available visibility data), the result of computations for the particular example used (an OD painted tank viewed against dry sand) do not appear credible. A 115-million candlepower flare is presumed in this analysis to be required which could hardly be cost-effective even if it were available. Far smaller flares than this have been successfully deployed for similar types of target acquisition. This disparity is due primarily to the unavailability of more appropriate data which forced Blunt to solve the problem at an over-conservative suprathreshold level where a lower level would have sufficed.

OBSERVER FACTORS

The last and possibly the most critical group of factors pertaining to the effectiveness of a target acquisition under flare light are those inherent in the visual and decision-making processes of the observer himself. Again, thesis subject matter has been reviewed in some detail by Blunt and Schmeling (1968) and Clisham (1969), and will not be covered extensively in this paper. Discussion here will be restricted to the geometric position of the observer's eye with respect to the target and/or the flare. Specifically, the points to be covered will be:

observer distance from the target, observer altitude, observer movement, and relative positions of the observer, target and flare.

Observer Distance from Target

This is the slant range from the observer at which the target is sighted and determines the visual angle of the object being viewed. The following formula may be used for computing this angle (θ) in minutes of arc.

$$\theta = 2\ \mathrm{ARCTAN}\frac{D}{2SL}$$

where D = Linear Dimension of target in feet
and SL = Slant range in ft.

Given a sufficiently long viewing range, θ will diminish to a value below resolution threshold. This occurs typically during daylight when the maximum dimension of the target projected to the eye subtends a visual angle of about one minute of arc.

However, under simulated MK24 flare light illumination with a simulated mist concentration of 3.0 particles/ml, Katz, et al. (1970) found the minimum visual angle for resolving a target to be about 1.5 minutes. Additional factors such as decreased illumination, flicker, target/observer motion might still further degrade target resolution and decrease minimal visibility ranges under typical flare mission conditions. More applied research needs to be done to clarify these matters. One such study has been reported by Davis (1971) where the illumination required to detect a target under simulated flarelight on a 1:160 scale terrain model was found to vary directly with the square of the slant range.

Observer Altitude

Part of the problem associated with slant range is the aircraft altitudes at which the observer views the target. If there are broad elevated features (e.g., mountains, towers) between the eye and the target, then sufficient altitude is obviously required to provide an unobscured view. Determination of this altitude would depend on knowledge of the terrain features and their dimensions. Another factor, which probably requires more research, is the effect on recognizability for particular target shapes as these are viewed in different air-to-ground perspectives at higher altitudes.

Hilgendorf (1971) has studied the effect of variations in observer altitude for resolving targets under simulated Naval MK24 flare-light. Subjects were required to resolve separations in Landolt rings and acuity gratings at eight simulated altitudes (from 500 to 4000 ft). Performance was measured as the response time from flare ignition to a correct acuity response. An intermediate altitude ranging from 2000 to 3000 feet was found to be optimal in this study. These results were confirmed by Hucker (1972) in a flight test at Eglin AFB.

Observer Movement

This is a critical factor (related to dynamic visual acuity) which requires systematic study.

Some data on the effect of aircraft speed on target acquisition have been provided by Clisham (1969) showing in general that increasing speed leads to decreases in detection range and detection probabilities. These data, however, were based on daylight acquisition and need to be rerun under flarelight conditions.

Relative Position of Observer, Target and Flare

An obvious planning factor is the relative position of the observer and the flare with respect to the target being viewed. The position of the flare as a glare source is one thing to be considered. This effect can be gauged both in terms of the intensity of the flare and its glare angle, i.e., the angle between the flare's line of projection to the eye and the observer's line of regard to the target. A glare source will produce a veiling luminance at the retina which is more deleterious to target acquisition the closer it is to the target image. Hence, the flare should be positioned with respect to the observer and the target so as to provide a relatively large glare angle. The smallest tolerable angle (which is usually greater than 7°) will increase with increasing flare brightness. This angle should be always smaller than the glare angle which exists at the burn-out altitude. The Illuminating Engineering Society (Kaufman (1972)) has defined the amount of veiling luminance L_v attributable to glare as follows:

$$L_v = \frac{K\,E}{\Theta^{(3/2)}}$$

where K refers to a constant (depending on the units being used) E to flare luminance and Θ to the glare angle.

Davis (1971), using the 1:160 scale terrain model and flare-simulating facility at Picatinny Arsenal, provides systematic data on the amount of ground illumination required for the recognition of vehicular and personnel-sized targets as a function of the target illumination angle, range, terrain background and angle of observation. Observers were positioned at a fixed distance and elevation for each test. The simulated flare was placed in a particular orientation with respect to both observer and target. The observer then increased the flare's intensity up to the point of target recognition. Typical results appear in figure 20 showing that a progressively smaller amount of flare light is needed to recognize the target as the flare moves from a position between the target and the observer at a target illumination angle of 30 degrees, through an overhead position at 90 degrees, to a position well-behind and above the target at 150 degrees. Similar tests were made with variations in observer elevation, target/background contrast, type of target (personnel vs vehicle) and slant range. Results of these tests are graphically portrayed in 17 figures appearing in Davis' report.

One way of expressing the advantage of deploying the flare behind the target is that the flare silhouettes the target rather than illuminating it. Strauss and DeTogni (1962) in an observational field test of a small flare (50,000 cp) noted that silhouetted targets (situated in front of the flare) are more frequently detected than illuminated targets (in back of the flare) at equal distances from the flare. It would seem likely that the acquisition of targets with pronounced vertical features (e.g., towers) would benefit most from the silhouetting mode of flare deployment.

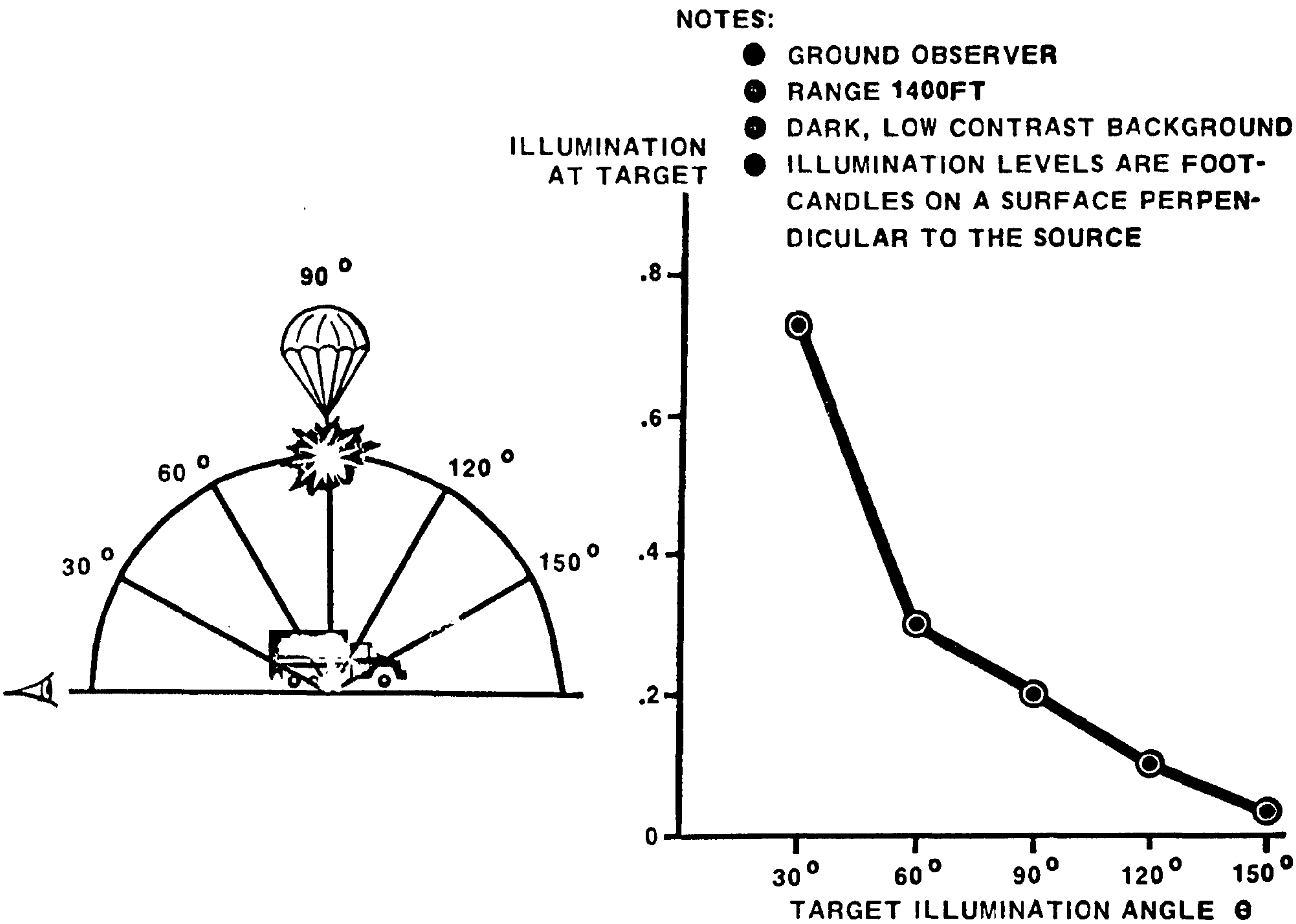

Figure 20. Illumination Required for Recognition as a Function of Target Illumination Angle

SECTION IV

CONCLUSIONS

In this paper an attempt has been made to extract, integrate and evaluate data from current research which pertains to the more effective design and utilization of illuminating flares. The principal criterion of effectiveness is the improved capability for air-to-ground visual acquisition of targets. Various research techniques for gathering data on flare effectiveness have been considered and relevant factors have been reviewed under the major headings of candle composition, deployment, wind drift, atmosphere, target and observer.

The information contained in this report is addressed to those Armed Forces personnel who study, design and use systems involving illuminating flares for target acquisition. In addition to providing them guidance on flare effectiveness, an effort has been made to review current research programs and to suggest areas requiring further investigation.

A disportionate amount of pyrotechnic research apparently has been expended in areas related to composition development and parachute deployment with too little concern for the amount or type of illumination actually needed to acquire a target. On the other hand, relatively little effort has been expended, within the context of mission requirements, which relates flare effectiveness factors to the responses of human observers. Without knowledge of such relationships, one cannot confidently evaluate the relative merits of alternative flare systems or of proposed innovations.

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APPENDIX A

AIRCRAFT FLARE DESCRIPTIONS

1. XM170 AIRCRAFT PARACHUTE FLARE:

a. Description. The XM170 Aircraft Parachute Flare (Fig A–1) is 35 inches long, 2.75 inches in diameter and weighs 12.5 pounds. It consists of five major sub-assemblies, the XM715 MT Fuze, two separate candles, a parachute housing assembly and a quickmatch initiation transfer system. The sub-assemblies are structurally attached to each other by the rubber-die crimp method with the exception that the fuze has a threaded interface connection. The flare is designed in such a manner as to make the use of an outer case unnecessary.

The XM715 MT Fuze (Fig A–2) consists of a zinc die cast housing which contains an interlock, a cover retainer detent system, a mechanical timer, a fuze functioning pilot parachute, an explosive firing train and a cover for time setting adjustments. Six safety interlock systems are incorporated into the fuze assembly.

The Candle and Parachute Assembly consists of illuminating candles attached to a parachute housing and a closure plug for one end and a fuze adapter on the other end. The illuminating candles, two per flare, utilize aluminum cases for an outer case, contain a magnesium based illuminating composition, and have a first fire composition pressed into the candle's face. One candle has an aluminum fuze adapter crimped to the aluminum case, and the other candle's face is sealed with an aluminum closure plug crimped to its case.

The parachute Housing Assembly is an aluminum container with a blow-off-door and a parachute in a rubber bag which protects it from the hot ejection gases. The blow-off-door is held in place by aluminum bands that break when the ejection charge is activated. The main parachute is attached to the candle assembly by two bolts, one of which contains an explosive charge that when initiated by candle burnout, releases half of the parachute suspension lines, thus causing the residual hardware to descend rapidly to the ground.

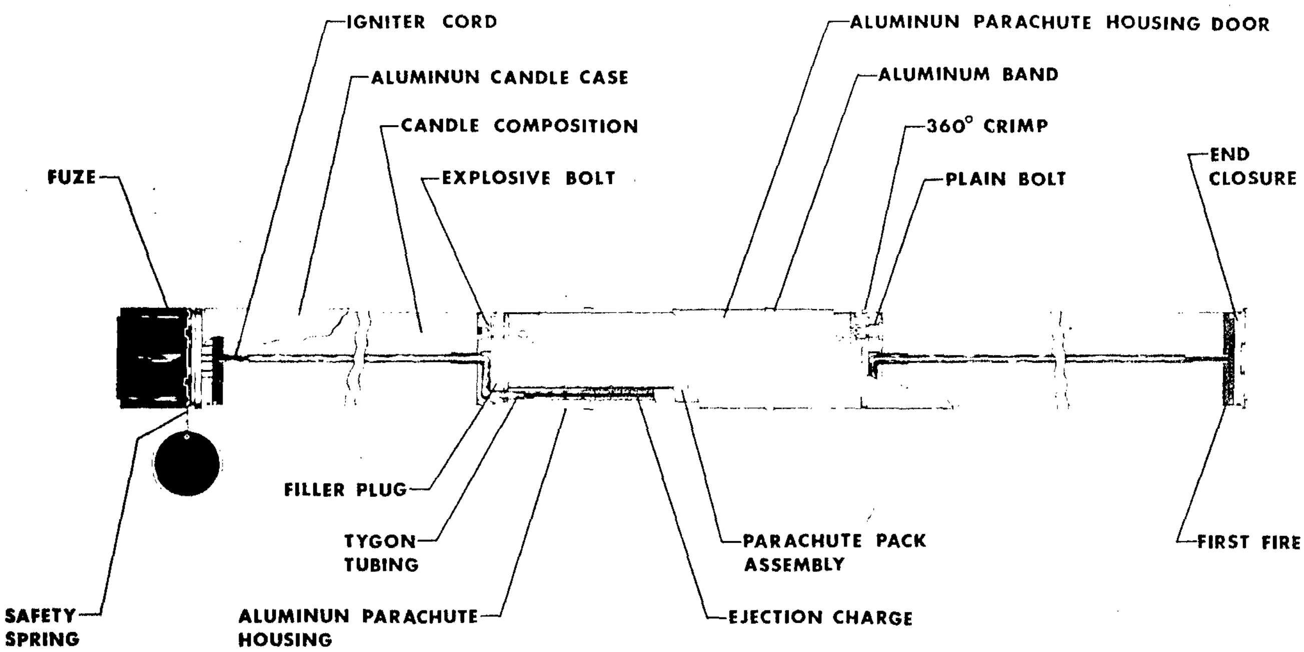
The XM127 Aircraft Flare Dispenser (Fig A–3) consists of a SUU–7 strongback which has mounting provisions for the standard 14-inch aircraft suspension lugs, 19 SUU–14 type tubes and heavy skin which forms the main reinforcing member. The dispenser will be assembled using a liquid foam to hold all parts in their proper positions.

The weight of the empty and the fully loaded XM127 Dispenser is 105 and 333 pounds, respectively.

The XM18 SUU–14/A) Dispenser (Fig A–4), either in a single (XM18) configuration or in a double (XM15) configuration as shown, may also be used to deliver the XM170, by loading two rounds per tube (these are simultaneously ejected on activation).

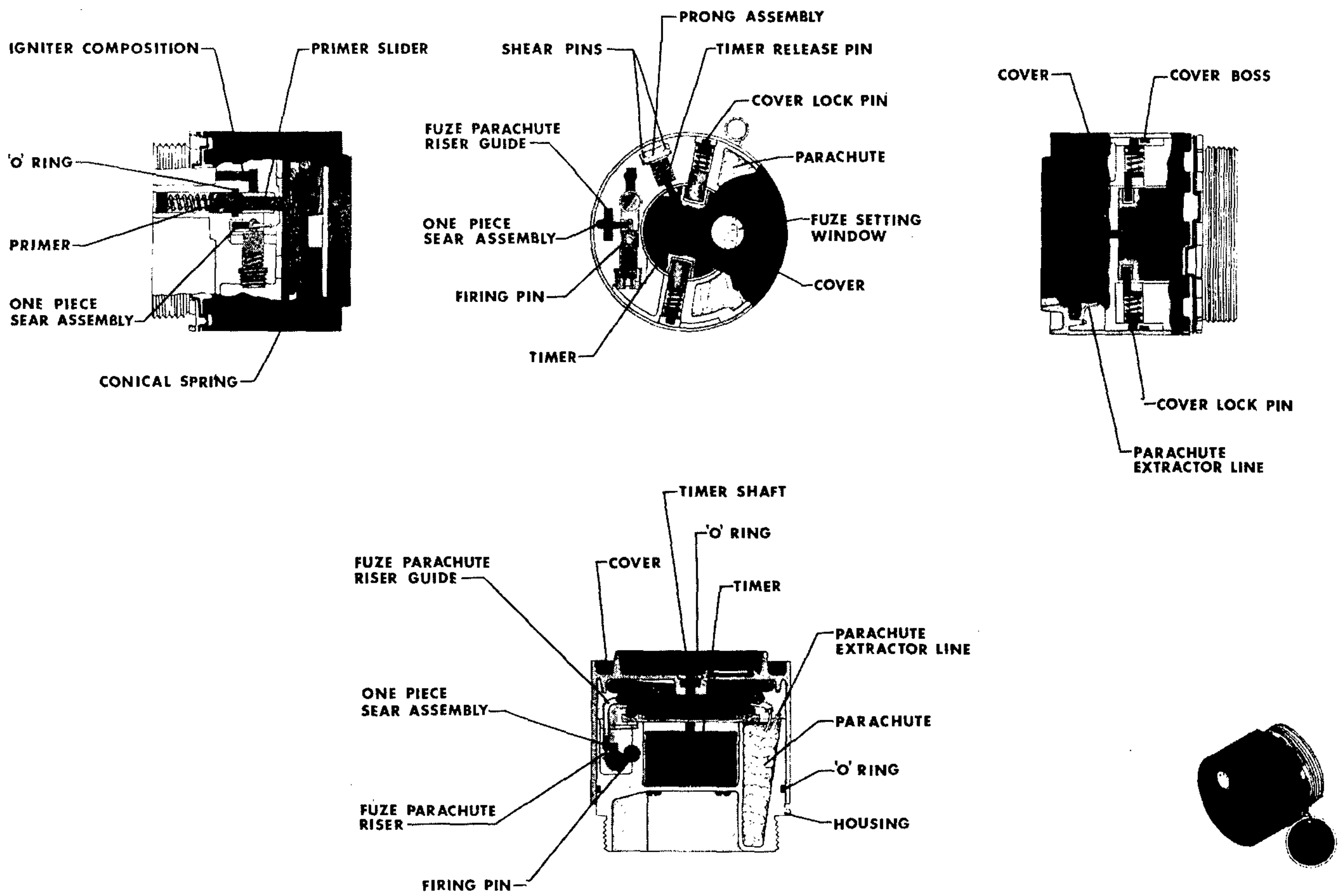
b. Functioning (Fig A–5)

(1) Dispenser Functioning. Prior to leaving on a mission, two XM127 Aircraft Dispensers,



XM170 AIRCRAFT PARACHUTE FLARE

FIG A–1



XM-715 MECHANICAL TIME FUZE

FIG A-2

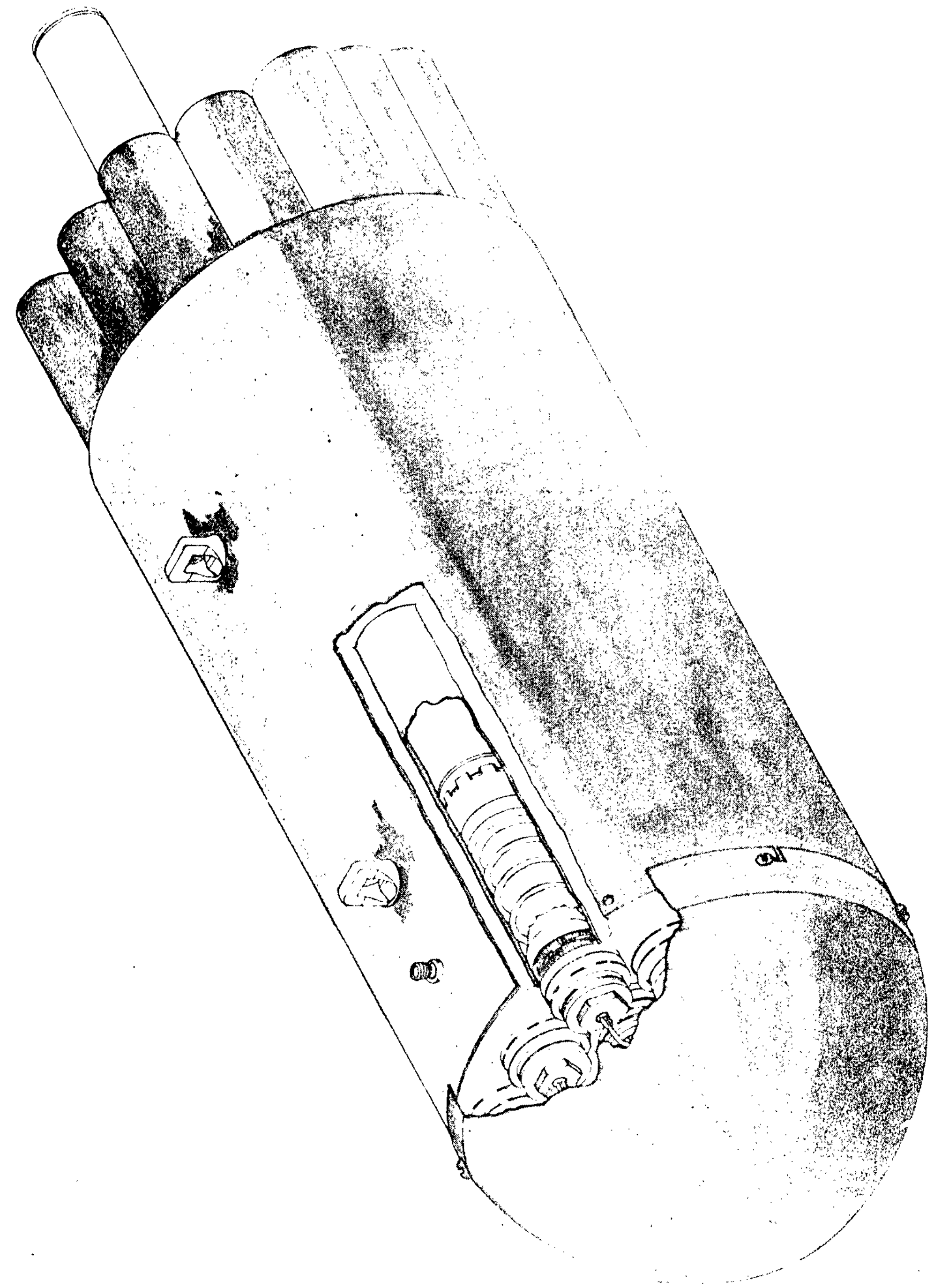
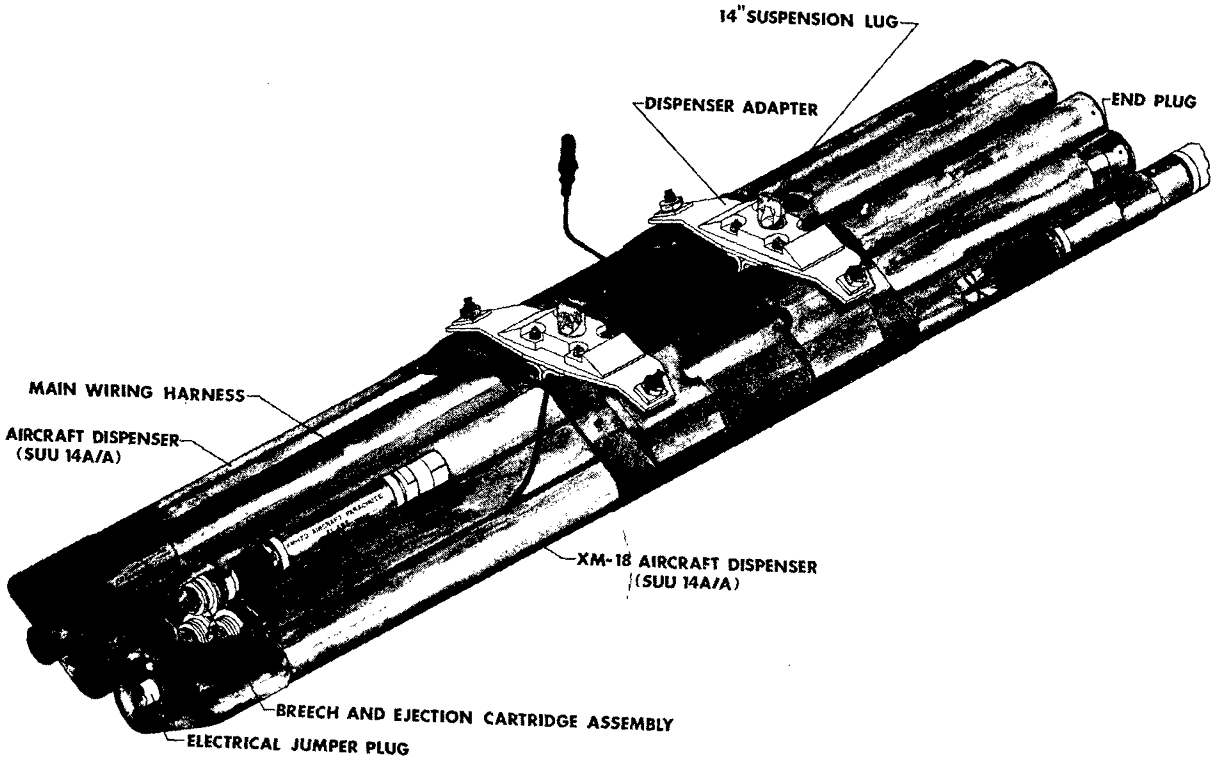


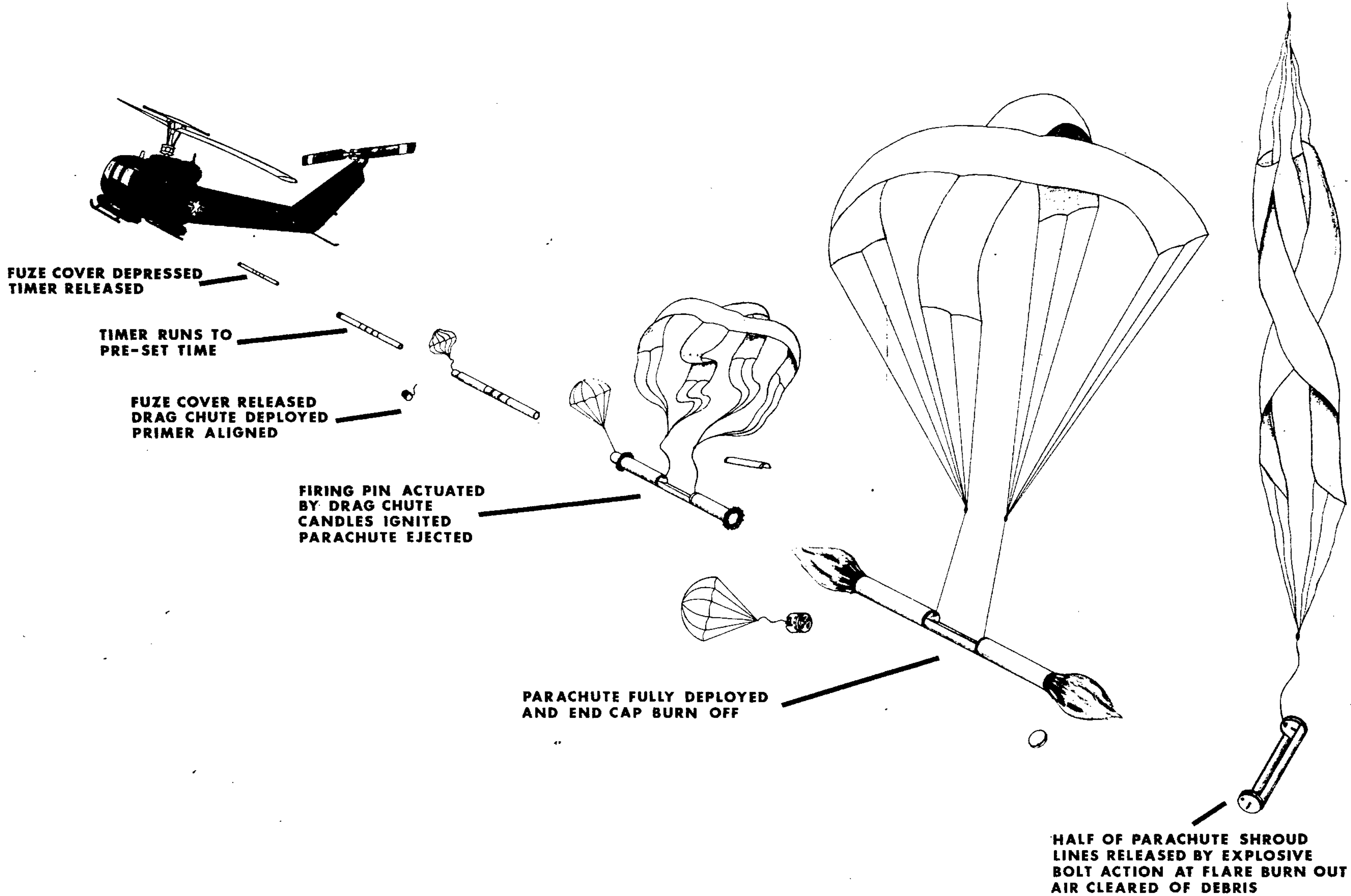
FIG A–3

919/1710



XM-15 AIRCRAFT DISPENSER AND FLARE

FIG A-4



XM170 AIRCRAFT PARACHUTE FLARE DEPLOYMENT SEQUENCE

FIG A–5

fully loaded with XM170 Aircraft Parachute Flares, are mounted on the Aircraft's external suspension system and connected electrically to the appropriate fire control circuit. The aircraft's fire control circuit has two switches, exclusive of the firing button, an arming switch, which shorts out the firing circuit until placed in the armed position, and a selector switch which allows the choice of a single flare from either left, right or both dispensers. These switches can be set, reset or changed anytime during the mission.

In operation, the pilot triggers his firing button on the control panel which closes a circuit from a power supply to the externally mounted dispensers. The firing command pulse passes through a RADHAZ filter and the arming switch (in the armed position) to the selector switch which is always set for single tube fire of either the left, right or both dispensers. The firing pulse then goes through the rotary selector switch and activates one of the ejection cartridges. The ejection cartridge builds up a high pressure behind the obturation piston and spring assembly and after providing enough force to shear the end plug rivets, ejects in order, the end plug, one XM170 Aircraft Parachute Flare and the piston and spring assembly.

(2) Fuze Functioning. When the dispenser tube is activated, the ejection charge gas pressure against the fuze cover is sufficient to completely compress the conical spring by moving the fuze cover forward; this will move the interlock assembly to the released position, releasing a pin in the timer's gear train and thus allowing the timer to function. The conical spring at this point has moved the fuze cover forward against the two cover retaining pins. When the previously set time is reached by the mechanical timer, a cam within the timer releases the two cover retaining pins. These pins are spring-loaded and move radially inward when released by the cam, freeing the fuze cover. As the cover is pushed off by the conical spring, two separate parallel actions transpire, the out-of-line primer moves into alignment with the firing pin, and a parachute extractor attached to the fuze cover pulls the fuze parachute out of its cavity and aids in its opening. The resultant opening shock force of parachute deployment, shears a pin and rotates a sear mechanism away from the spring-loaded firing pin. The firing pin, thus released, impinges upon the now aligned percussion primer, which propagates to a two second delay (allowing the fuze parachute to stabilize and retard the round). The delay transfers to an ignition composition containing granules of boron-potassium nitrate. The resulting total output of the propagating ignition composition is directed toward the aft end of the fuze housing.

(3) Flare Functioning. When the fuze functions, the output of particles and gases simultaneously ignites both the first fire of the nearest candle (which blows off the fuze adapter) and the quickmatch transfer line. The transfer line instantly ignites both the black powder parachute ejection charge and the second candle's first fire (which blows off the end closure). As the ejection charge burns, it forces the parachute against the blow-off-door, finally shearing the aluminum bands. As the door is ejected, it pulls out the parachute and aids in its deployment through the use of a deployment ribbon attached to the door and folded into the parachute assembly. The parachute now suspends the flare system in a horizontal mode leaving the candles to provide useful illumination. As the candles burnout, one candle ignites an explosive element in one of the parachute attachment bolts, freeing half the parachute shroud lines. Freeing half of the parachute shroud lines allows the parachute to spill its air, collapse and utilize the weight of the aluminum center section to aid in its descent to the ground, thus removing the hazard that expanded parachute flares normally present to operational aircraft.

2. M8A1 AIRCRAFT PARACHUTE FLARE

a. Description. The M8A1 Aircraft Parachute Flare (Fig A–6) is 25.42 inches long by 4.25 inches in diameter and weighs 17.6 pounds. The flare consists of a candle, parachute assembly and two friction igniters. This item does not contain a delay type time fuze.

The illuminant charge weighs 10 pounds and is contained in a paper tube encased in a zinc sheathing. The illuminant composition consists of barium nitrate, magnesium, aluminum, sodium oxalate, and small percentages of linseed and castor oils. A quickmatch passes through the length of the center tube of the illuminant assembly and provides the means of relaying the flame from the igniters to the priming composition and thence, in turn, to the first-fire composition and illuminant charge. A top seal of fire clay separates the igniters from the illuminant charge.

The aluminum base block fits immediately over the top seal. This base block holds screws which fasten the parachute case to the illuminant case. The base block also is an anchorage for the suspension cable and contains the two friction igniters which consist of a friction composition and a friction wire coated with red phosphorus. One end of the friction wire is attached to the suspension cable above the shock absorber. So that an appreciable pull will be required to operate the igniters, the friction wires are secured against the base block by an aluminum safety strip secured, in turn, by a brass retainer. The shock absorber consists of the flexible steel suspension cable encased in a hand-drawn copper tube, the whole formed into a closely wound helix. A paper safety disk closes the cup housing the shock absorber assembly. The disk must be removed by a jerk on the suspension cable before the friction igniters will fire.

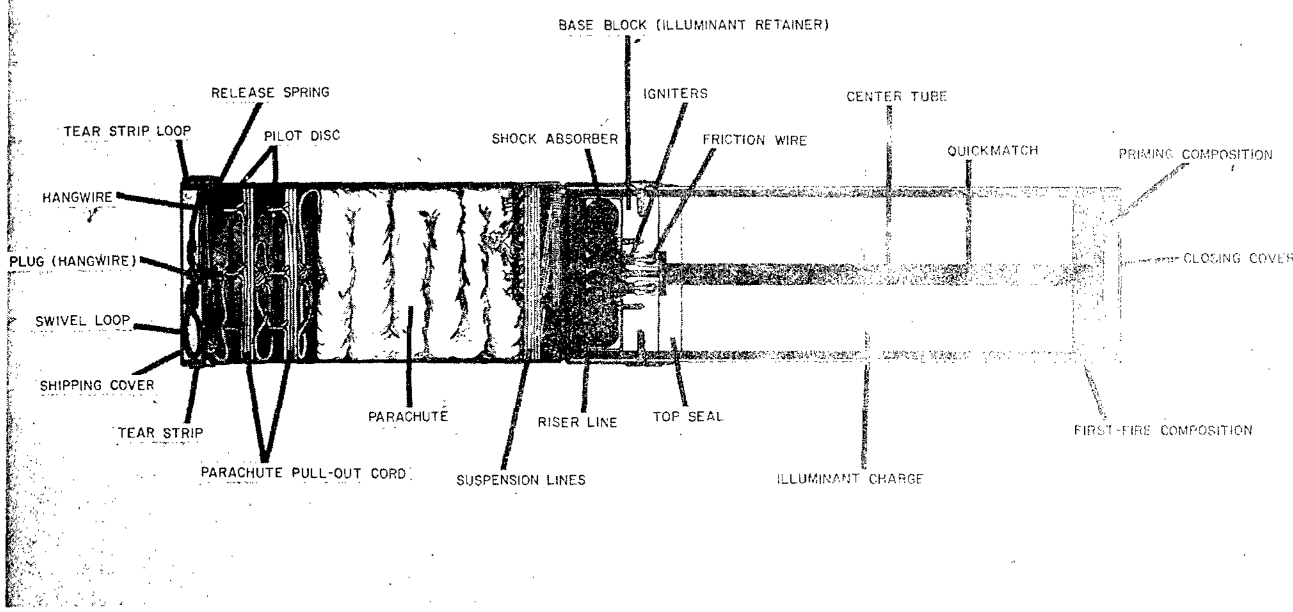
The parachute is made of silk or synthetic fabric and is 15 feet in diameter. The shroud lines are braided cotton cord. having a 100-pound breaking strength. The shroud lines are 14 feet in length and are attached to the suspension cable by means of the suspension cable spool. Two pilot disks, through which the parachute pullout cord passes, are assembled underneath the hangwire cover.

The parachute case is closed by the hangwire cover which is in the position of a cup opening outward. The hangwire with swivel loop is not permanently attached to the cover, but is assembled to the hangwire plug passing through a central hole in the cover and held by a release spring on the underside of the cover. One end of the release spring is held in a clip soldered or welded to the underside of the hangwire container. The other end passes through the central hole in the release plug. The release spring is held in this position by the parachute case. As soon as the hangwire cover is free of the case, the spring releases the hangwire plug, then the hangwire and its plug separate from the cover.

A shipping cover, held by a tear strip, protects the parachute case end of the flare. A closing cover is press fitted over the open end of the illuminant portion of the flare and is loose enough to be blown off when the composition begins to burn.

b. Functioning (Fig A–7)

When the flare is released from the aircraft, the hangwire cover is removed by the resulting



M8A1 AIRCRAFT PARACHUTE FLARE

FIG A–6

M8A1 AIRCRAFT PARACHUTE FLARE DEPLOYMENT SEQUENCE

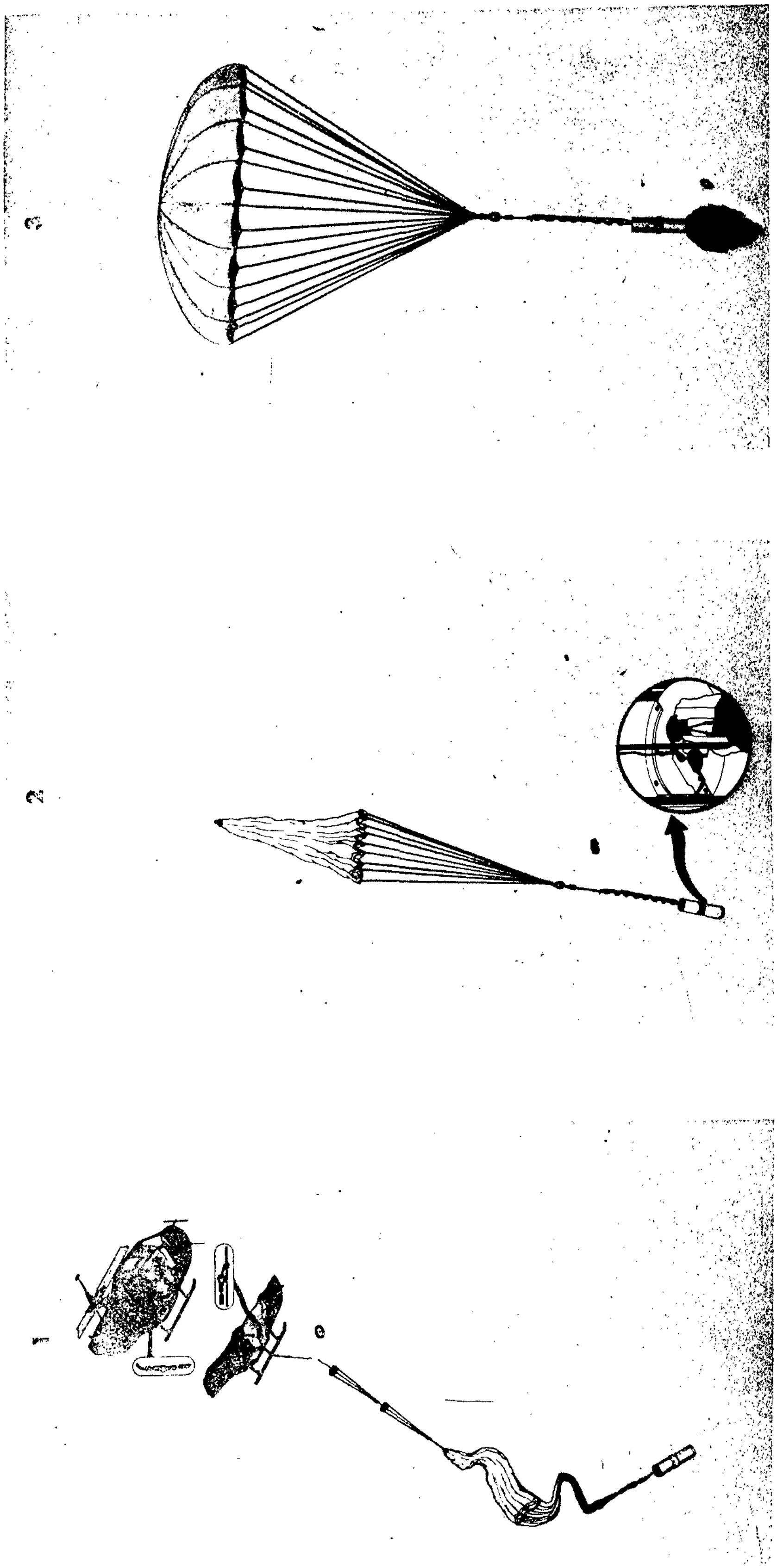


FIG A-7

jerk of the lanyard on the hangwire. The flare is now free of the aircraft. The pilots disks and parachute pull-out cord withdraw the parachute from its case and the parachute deploys. As soon as the hangwire cover leaves the case, the release spring pulls away from the hangwire plug and the cover is free to fall away from the hangwire.

The sudden pull of the deployed parachute causes the suspension cable, shock absorber assembly and safety disk to pull out of the case, and simultaneously cause the friction wire to pull through the friction composition.

The resultant flame is transmitted by the quickmatch to the priming composition and, in turn, to the first-fire composition and the illuminant charge. The pressure produced by the burning composition blows off the closing cover on the illuminant end of the flare, resulting in proper candle operation.

3. LUU–2/B AIRCRAFT PARACHUTE FLARE

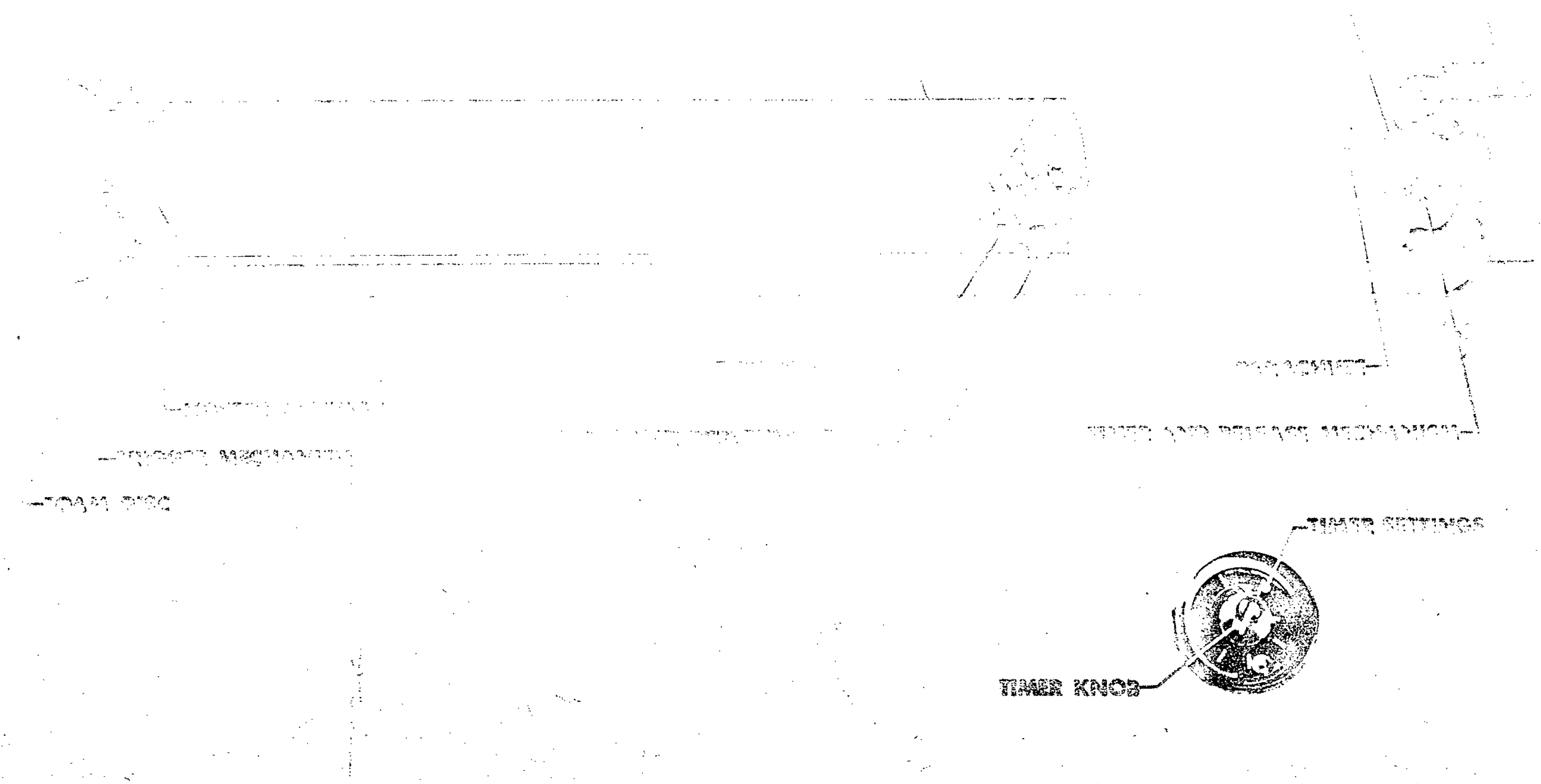
a. Description. The LUU–2/B Aircraft Parachute Flare (Fig A–8) is 36 inches long, 4.87 inches in diameter and weighs approximately 29½ pounds. The flare consists of four major subassemblies, the timer-end cap assembly, the parachute suspension system, the ignition system and the case assembly with the tamped candle. The flare is designed so that the outer aluminum case is partially consumed during candle burning.

The timer-end cap assembly consists of a timer and related hardware enclosed in a lexan plastic housing. The setting dial knob and calibrated markings (from 500 to 10,500 feet of fall) are coated with a luminous paint which has an after glow from 8 to 10 hours after being exposed to light. The timer consists of a simple clock mechanism in which the main spring is wound tighter, if more than a 500 foot free fall is desired, as the timer dial knob is set to the desired drop distance. The timer is kept at a 500 foot setting during storage. A small drogue bag is packed in a compartment located in the timer cover. The plastic cover over the drogue bag compartment is removed when the timer dial knob is pulled. The purpose of the drogue bag is to prevent the flare from developing an excessively high rate of tumbling; thus, should tumbling reach 100 to 200 revolutions per minute, the drogue bag is deployed.

The parachute suspension system utilizes an 18 foot diameter cruciform shaped canopy, for good stability. Two riser cables connect the parachute to a bulkhead separating the parachute compartment from the remainder of the flare assembly. One cable is attached to an explosive bolt for parachute dump at candle burn out.

The ignition system utilizes a lanyard, which is attached to one of the parachute riser cables. This lanyard is led through the bulkhead and past the candle in an internal raceway along the side of the aluminum case leading to the ignition assembly in the ignitor housing near the candle's face. The lanyard is attached to a triggering mechanism consisting of a bell crank, firing pin housing, firing pin spring, shear pin, pivot pin and primer. The firing train sequence of propagation is primer–ignition pellets–ignition wafer–candle composition.

The illumination candle is a tamp cast sodium nitrate–magnesium pyrotechnic composition



LUU-2/B AIRCRAFT PARACHUTE FLARE

FIG A–8

which is loaded directly into the flare's lined out aluminum container. The candle grain is approximately 22 inches long.

b. Functioning (Fig A–9). During dispenser up-loading, a lanyard is attached to the dial knob on the flare timer. At launch; the timer dial knob is pulled out of the timer (approximately 35 pounds force), starting the clock mechanism. After the preset time (drop distance) has elapsed, the three locking pawls in the timer assembly, which are maintained in place by a rotary cam, are released.

The three pawls retract releasing the timer-end cap assembly. The spring, located between the timer assembly and packed parachute, expels the timer assembly which is attached to the top of the parachute by a cord having sufficient strength to initiate removal of the parachute from the flare case and subsequently breaking to separate the timer assembly from the parachute.

As the parachute system deploys and its main cables are pulled taut, the ignition lanyard, having insufficient slack to accommodate the cable movement, is pulled to activate the ignition system. The ignition lanyard must exert a force of 50 pounds to break the shear pin. Then, the ignition lanyard rotates a bell crank which cocks and releases the firing pin against the primer. The primer ignites a small charge of pelletized boron–potassium nitrate, which in turn ignites a propellant wafer, which produces sufficient heat for candle ignition.

Pressure build-up during candle ignition blows out two pressure relief plugs in the ignitor housing. Most of the ignitor housing is consumed by the burning flare; however, the last small pieces of the aluminum ignitor housing fall free. Just before candle burn out, the explosive bolt functions to release one of the suspension cables causing the parachute to dump.

4. MK45 AIRCRAFT PARACHUTE FLARE

a. Description. The MK45 Aircraft Parachute Flare (Fig A–10) is 36 inches long, 4.87 inches in diameter and weighs 28 pounds. The flare consists of a fuze assembly, an outer container, the candle assembly, a suspension ignition assembly and a parachute assembly.

The fuze assembly is used to control the ejection altitude in relation to the launch altitude. it does not directly control candle ignition. The fuze consists of an internal disconnect, a striker and plunger assembly, a 1.5 second minimum fixed delay element, a time delay fuze cord and an expelling charge. Fuze setting is accomplished with a single yellow dial indicator which can be set at 15 different positions (500 to 14,000 feet of fall). Raised projections at SAFE and at each setting point facilitate setting the fuze in total darkness. A spring loaded detent holds the dial indicator at the selected setting.

The outer container is an aluminum tube sealed at one end by an O-ring and the fuze assembly, and at the other end by another O-ring and an aluminum cap.

The candle assembly, consisting of the illuminating composition, candle case and explosive bolt assembly, is located directly behind the fuze assembly in the forward half of the outer container. The candle's ignition surface is faced away from the fuze end of the outer container

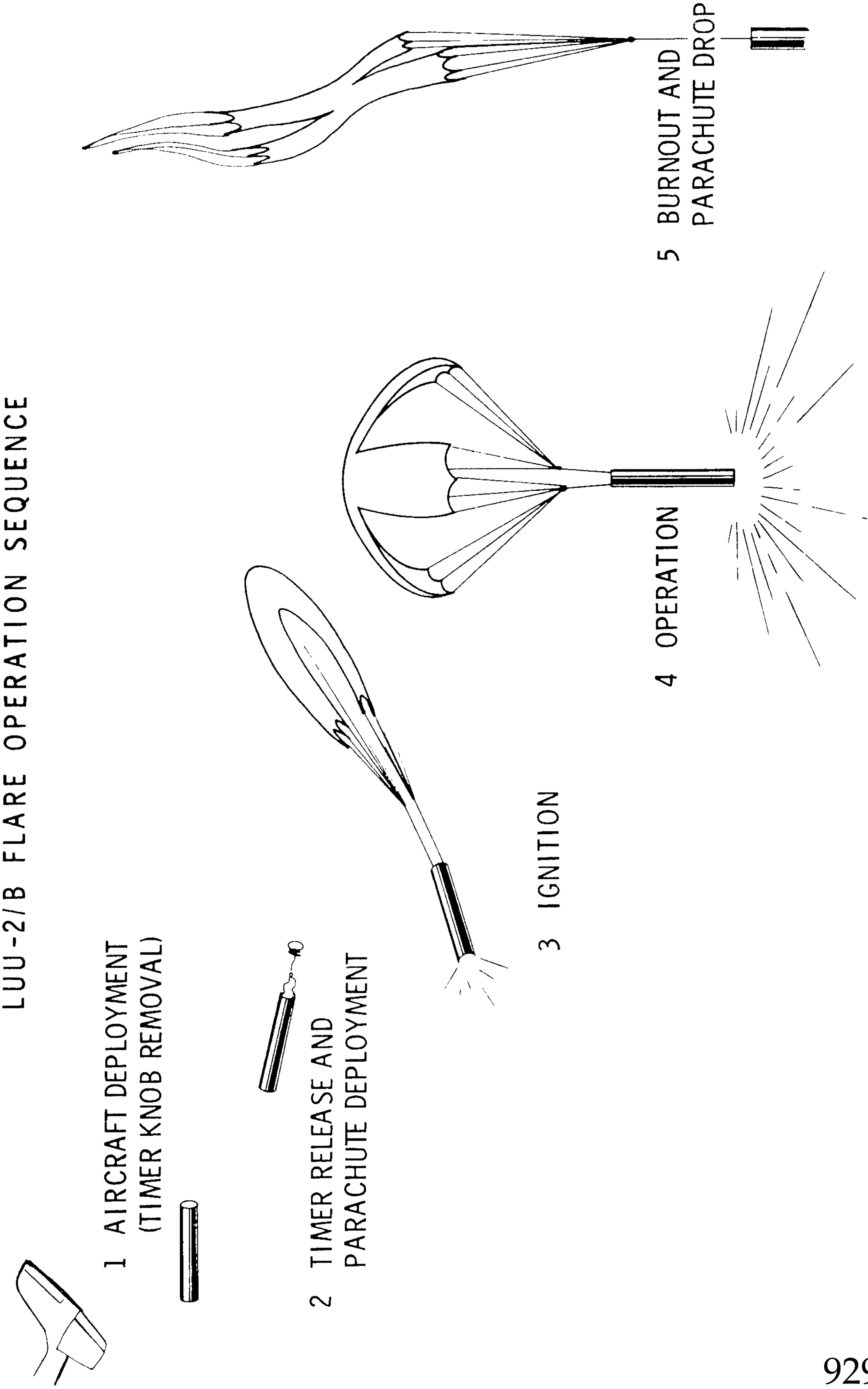


FIG A–9

929/1710

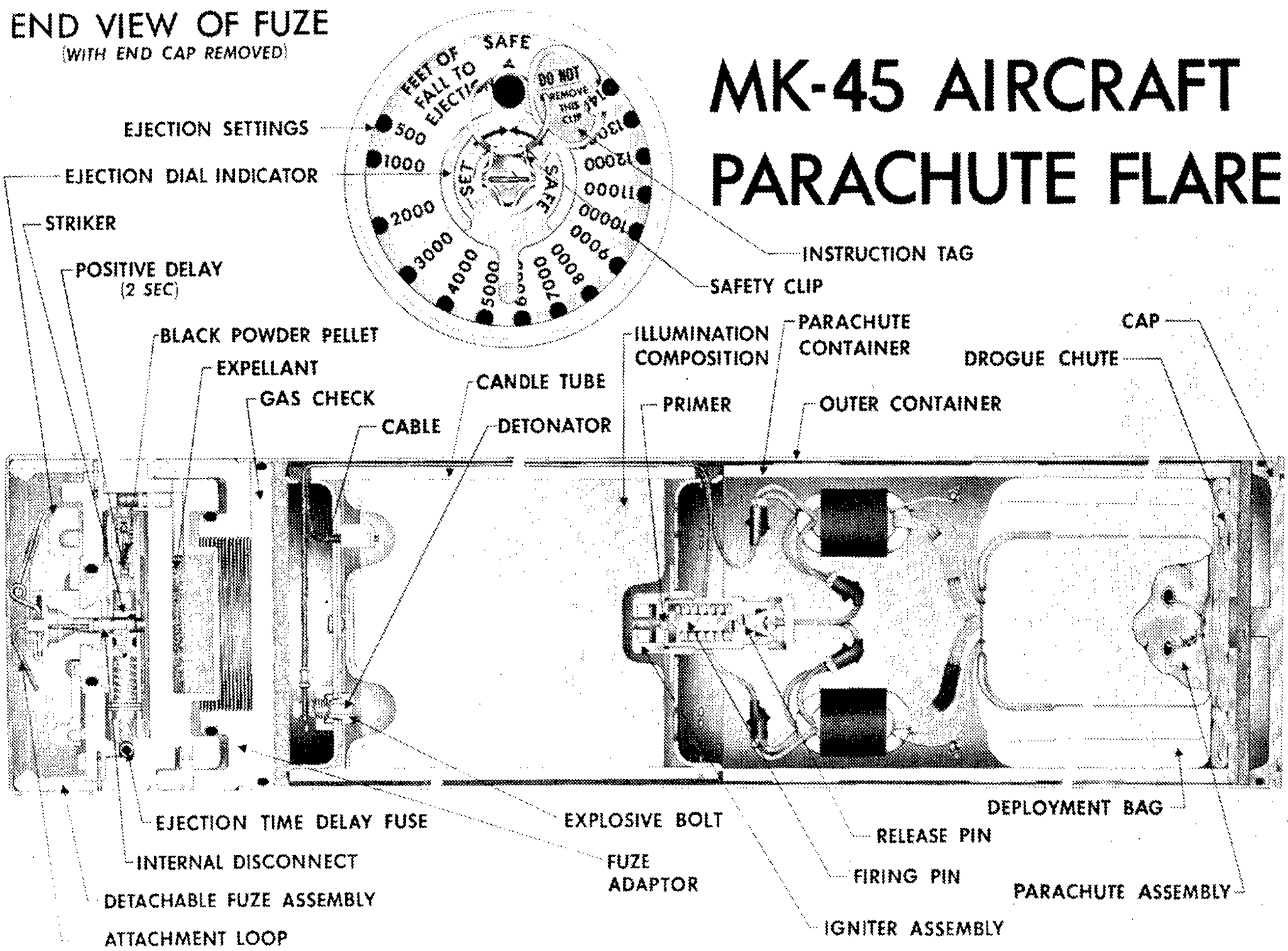


FIG A–10

930/1710

and a gas check is used to insure that ejection charge gases do not prematurely ignite the candle.

The suspension and ignition assembly consists of a release pin, a firing pin, a primer and a suspension cable. The first three items are located in a housing on the candles ignition face and the suspension line attaches them to the parachute assembly.

The parachute assembly consists of a drogue chute, a main parachute, a deployment bag and a split case; all located in the back half of the outer container.

b. Functioning (Fig A–11, A–12, A–13). When the flare is launched, the lanyard snaps the safety clip from its position over the toggle and exerts sufficient force (more than 30 pounds) on the attachment loop to release the internal disconnect from the fuze mechanism. Releasing the disconnect frees a spring loaded striker to function a primer in the base of the plunger. The primer ignites the 1.5 second fixed delay element and drives the plunger into the time delay fuze cord. When the delay element burns through, it propogates to a black powder charge (still in the plunger) and then to the fuze cord. After the fuze cord burns for the desired time (drop distance) setting it ignites the expelling charge, which in turn develops sufficient pressure against a gas check to blow off the end cap and expel the parachute, suspension/ignition and candle assemblies.

The drogue chute deploys, separating the main parachute from its deployment bag. As the main parachute is deployed, it exerts a force on the suspension/ignition system cable. The cable pulls the release pin from the igniter assembly, that cocks and releases the firing pin so that it strikes the primer. The primer initiates an ignition pellet which ignites the candle. The candle assembly then inverts itself to hang in a face down position directly below the parachute.

Near the end of its burning time, the candle activates an explosive bolt that releases 10 of the 18 parachute shroud lines, thus collapsing the parachute.

5. MK24 AIRCRAFT PARACHUTE FLARE

a. Description. The MK24 Aircraft Parachute Flare (Fig A–14) is 36 inches long, 4.87 inches in diameter and weighs approximately 27 pounds. It consists of eleven major and minor subassemblies as follows; an outer case, a weather cap, a desiccant bag, a lanyard assembly, an ejection fuze, an ignition fuze, a candle assembly, a parachute assembly, a cable assembly, a compression pad and an end cap.

The outer case is a one-piece aluminum tube which houses the complete flare and fuze assemblies. An "O"-Ring seal is provided between the ejection fuze assembly and the outer case in an attempt to assure the internal integrity of the round.

Held in place by a moisture proof tape is the weather cap which is a vacuum formed plastic piece that is used to protect the fuze end of the round during shipment and storage.

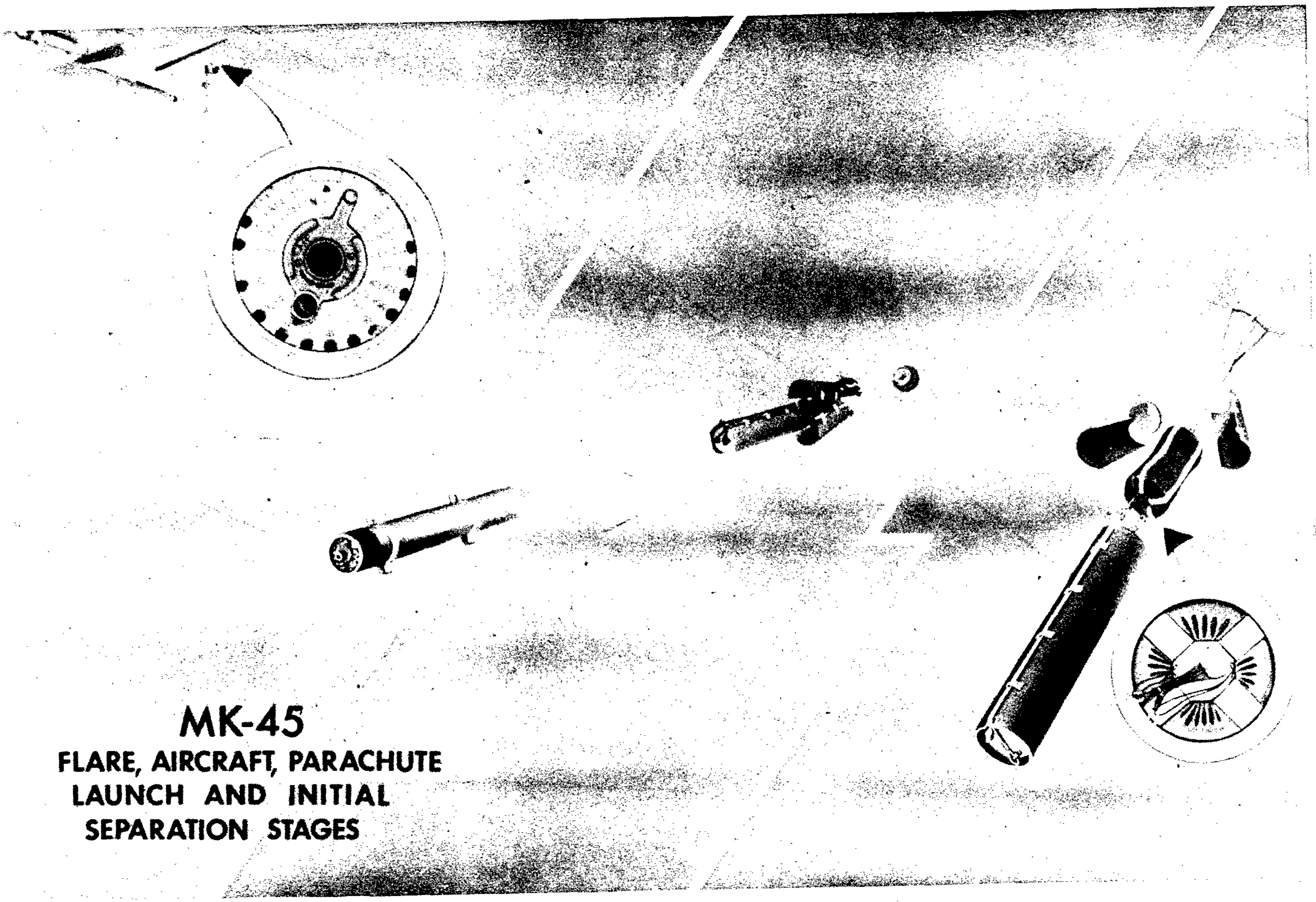

MK-45
FLARE, AIRCRAFT, PARACHUTE
LAUNCH AND INITIAL
SEPARATION STAGES

FIG A–11

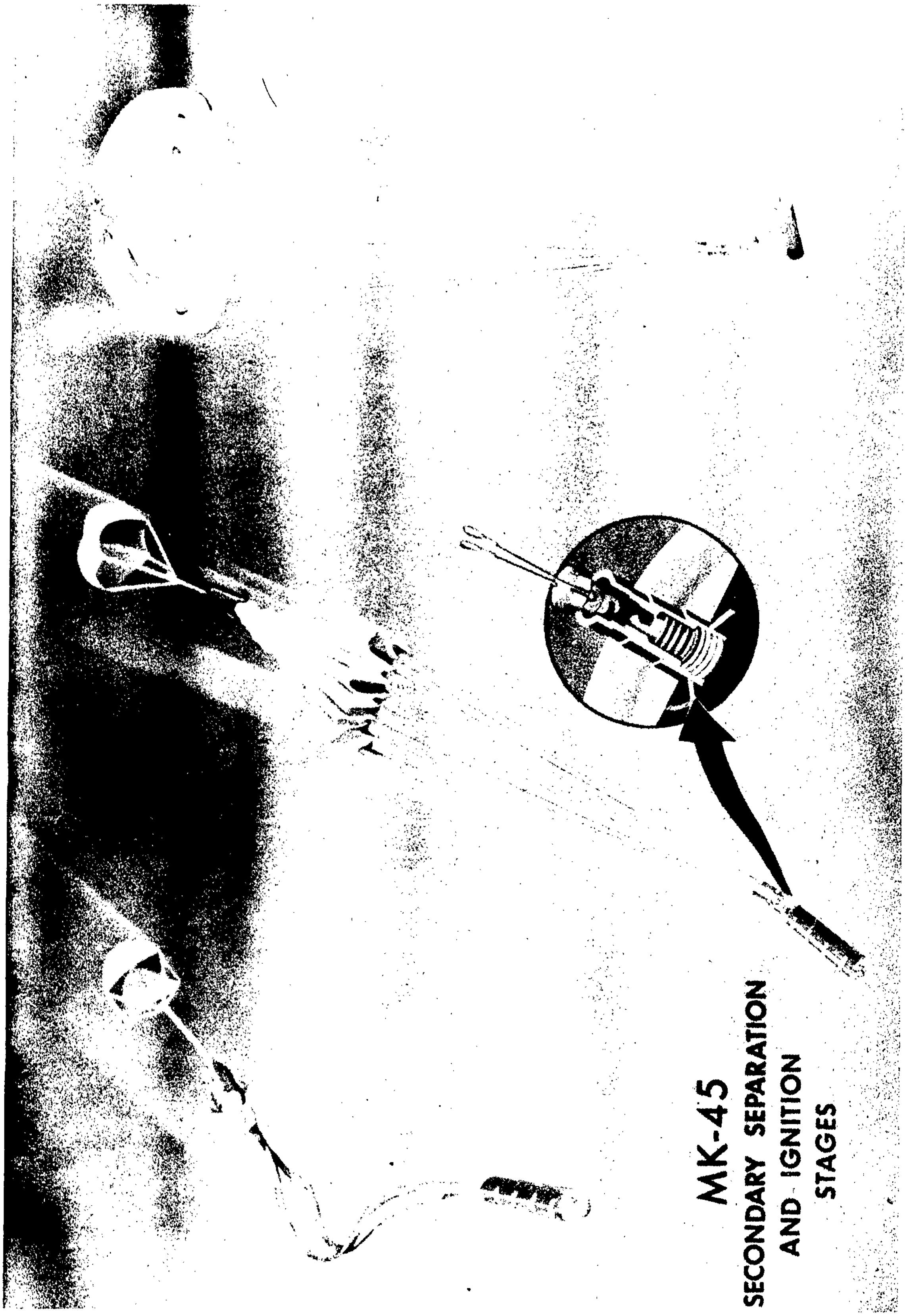


FIG A–12

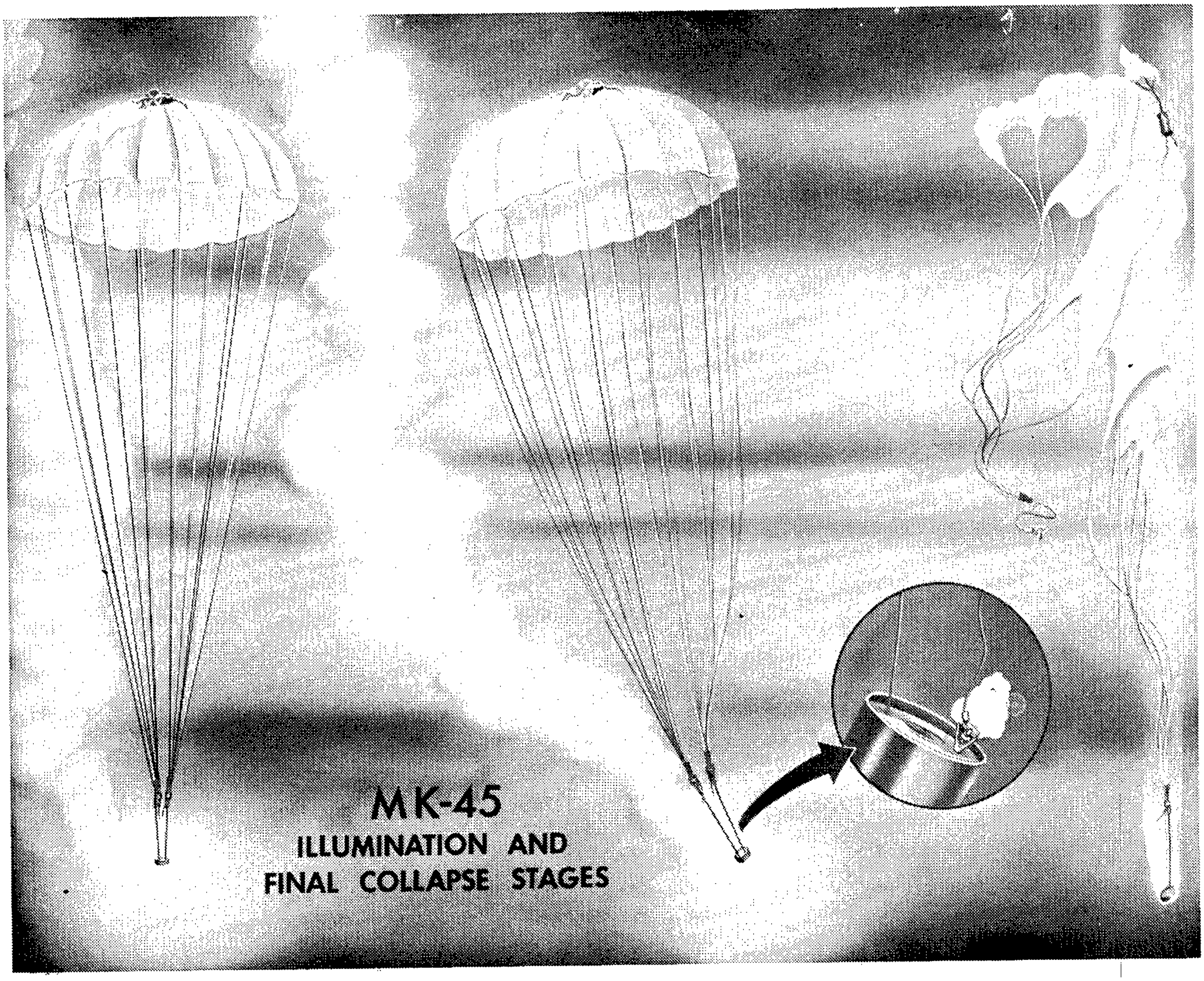
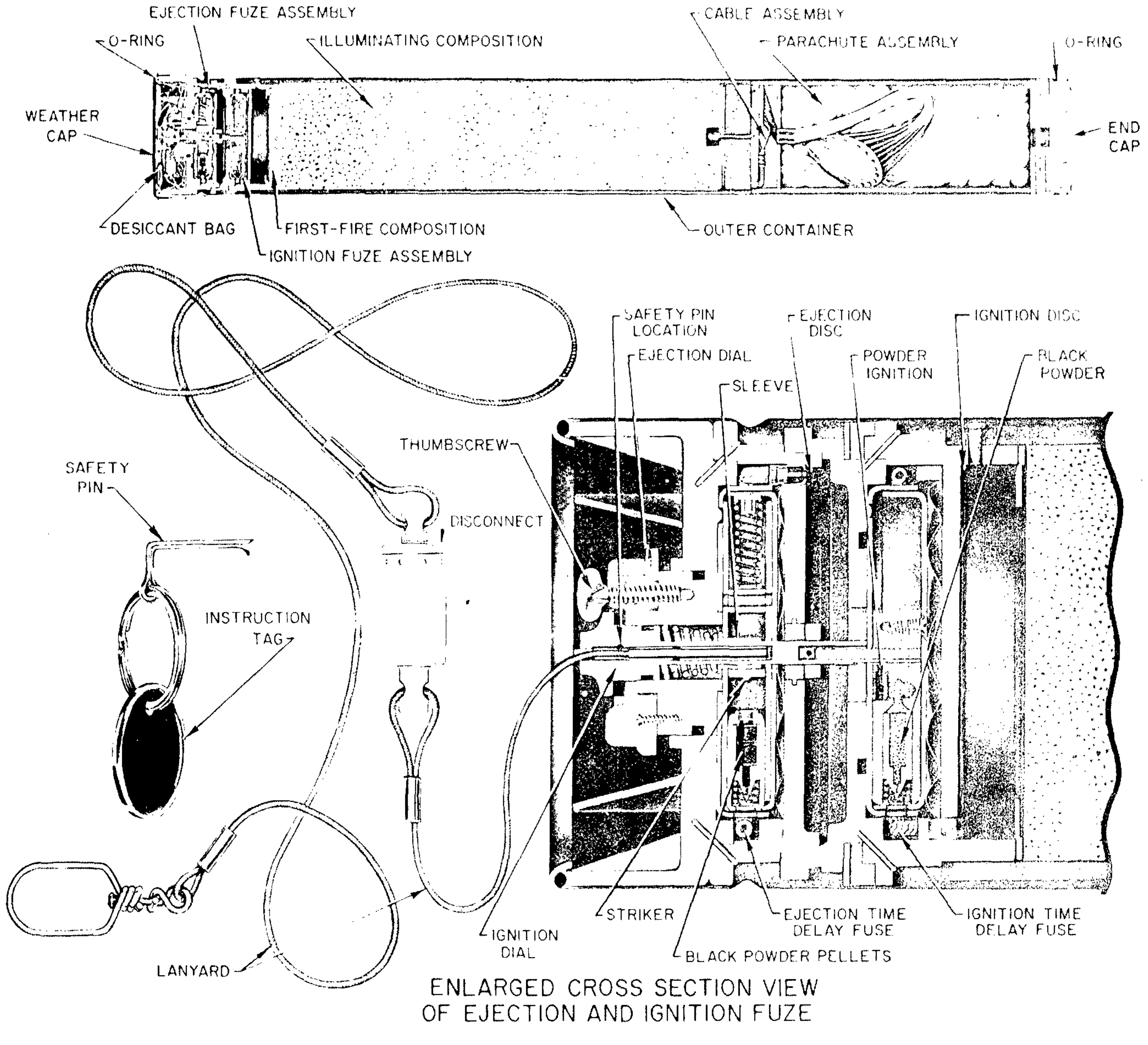


FIG A–13



AIRCRAFT PARACHUTE FLARE, MK 24, CROSS-SECTION

FIG A-14

The desiccant bag is utilized to protect the fuze assemblies from moisture during shipment and storage. It is located between the weather cap and the ejection fuze.

Also located between the weather cap and the ejection fuze is the lanyard assembly, which consists of two flexible, stainless steel cables (7 and 27 inches long, respectively) joined by a disconnect which releases between 55 and 75 pounds force.

Located at the forward end of the round, directly below the fuze dials, is the ejection fuze assembly. Consisting of an ejection plunger and housing assembly, a delay fuze line and an ejection charge assembly. It controls the candle and parachute ejection from the outer case. The ejection fuze dial is yellow with a black arrow which points to the outer ring of black figures on the fuze dial. It contains a thumbscrew, for dial locking, which passes through the yellow ejection fuze setting dial. The ejection fuze has a range from 5 to 30 seconds in five second intervals.

Controlling candle ignition is the ignition fuze assembly, which is located directly below the ejection fuze assembly. It consists of an ignition plunger and housing assembly, a delay fuze line, and an ignition composition assembly. The ignition fuze setting dial is painted black with a white arrow which points to an inner ring of white figures on a black background on the fuze dial. A spring steel safety pin is inserted through the bottom of the dial. The ignition fuze has a range from 10 to 30 seconds in five second intervals.

The candle assembly, located directly behind the ignition fuze, consists of a kraft paper tube filled with an illuminant composition of magnesium, sodium nitrate and epoxy binder. There is 16.2 pounds of composition contained in every candle. A wooden block is stapled inside the aft section of the candle tube for suspension system attachment.

The parachute assembly consists of a 16 foot diameter flat circular parachute in a split cardboard container. It is located directly to the rear of the candle assembly.

The cable assembly connects the parachute assembly with the wooden block in the candle assembly.

The compression pad, located between the parachute and the end cap, assures that all component manufacturing tolerances are taken up and all assemblies are held firmly in place.

Crimped to the aft end of the outer container is the aluminum end cap which, by means of an "O"-Ring seals the aft end of the round.

b. Functioning. When the flare is launched from the aircraft, it falls free for a distance equal to the length of the lanyard. When the pull of the flare on the lanyard reaches 12 pounds, the lanyard raises a sleeve in the ejection fuze. This permits a spring-loaded striker to hit the percussion primer, which initiates the fuze cord according to the ejection fuze time setting. During this time the force on the lanyard becomes large enough (55 to 75 pounds) to disconnect the flare from its static line. At the end of the preset delay, the ejection delay fuze ignites the ejection charge disc. Gases from the burning ejection charge disc forcibly eject (in order) the end cap, the compression pad, the parachute assembly with split cardboard con-

tainer, the candle assembly and the ignition fuze assembly. The ejection charge also propagates to an ignition charge on the ignition fuze assembly.

Upon ejection, the parachute opens and suspends the candle with the ignition fuze assembly attached. The ignition fuze burns for the time preset on the dial and ignites a gasless ignition powder. This powder in turn ignites the candle which then burns off the ignition fuze assembly and continues to burn for the appropriate burning time.

6. ATTACK AIRCRAFT PARACHUTE FLARE

a. Description. The Attack Aircraft Parachute Flare (Fig A–15) is 61.4 inches long, 8.00 inches in diameter and weighs 103.6 pounds. The flare consists of nine major sub-assemblies or components; a thin aluminum case, an illuminant tamp-cast into and bonded to the case, an ignition system, a main support parachute, a decelerator drogue parachute (with support line and five-second delay pyrotechnic reefing line center), a mechanical drogue release time assembly, an aerodynamic nose cone, a cast aluminum hardback and a set of four aerodynamically stabilizing fins.

The forward end of the flare utilizes the ogive nose cone to reduce aerodynamic drag during aircraft carry. The nose cone is hollow and contains two pressure relief ports. Attached to the aft end are four fins which provide aerodynamic stability during aircraft separation and free fall. The illuminant candle, ignition system, main parachute, drogue parachute and reefing line cutter are all contained within the eight inch diameter cylindrical aluminum case. The cast aluminum hardback is attached to the flare case by two band type coupler clamps, one at the ignition housing and one at the bulkhead between the candle and parachute compartments.

The main parachute support cables and the drogue parachute support line are attached to the case bulkhead. The aft end of the flare case is closed by a plastic cover which houses, and is released by, the mechanical timer and related fuze mechanisms. The flare candle compartment is lined with an asbestos insulation material and a mastic liner, prior to tamp casting the illuminant composition (magnesium, sodium nitrate and polyester binder). The candle end of the case is sealed by an O-ring in the igniter housing and the parachute compartment is sealed by an O-ring in the timer housing.

b. Functioning (Fig A–16). As the Attack Flare is released from the aircraft, the arming wire is pulled and the preset timer is initiated. When the flare has fallen the desired distance (500 to 9,000 feet), the timer and cover are released and ejected (by spring) from the aft end of the flare case. The ejecting timer pulls out the drogue parachute which is attached to the flare bulkhead.

The drogue parachute opening shock initiates a five second delay, which when burned through activates the reefing line cutter, releasing the drogue parachute from the bullkhead. The drogue parachute then pulls ou the main parachute. The shock of the main parachute deployment causes flare ignition. The nose cone and igniter assembly are consumed during the initial period of candle burning. An explosive bolt is initiated 20 seconds prior to candle burnout and dumps the main parachute.

ATTACK FLARE

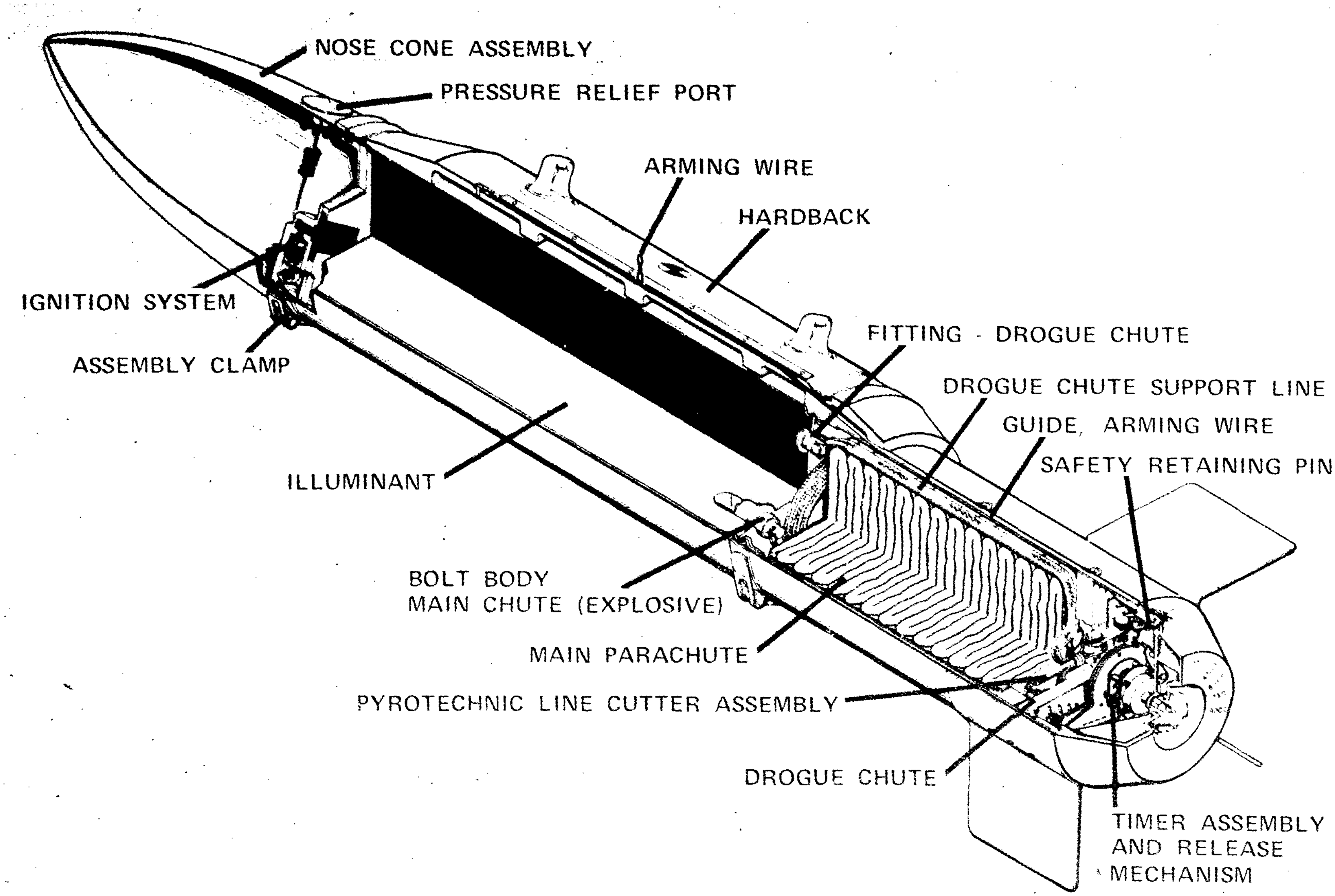
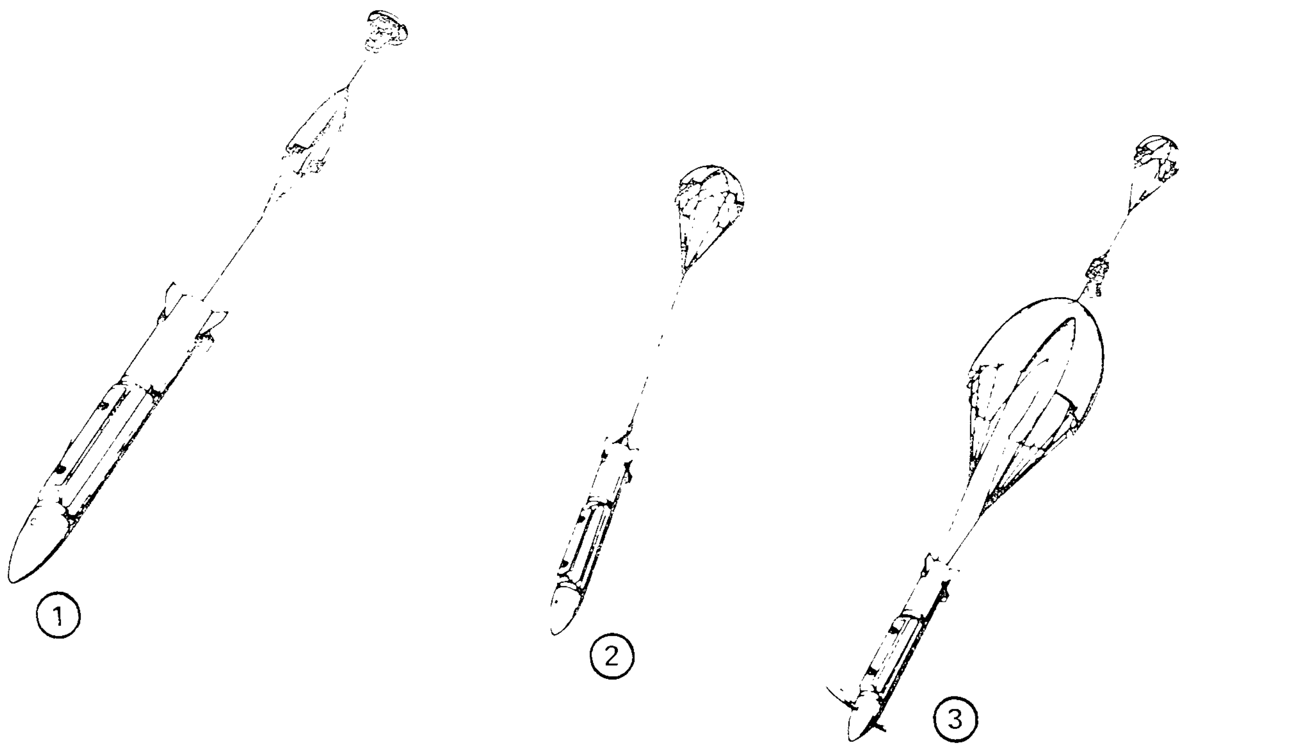
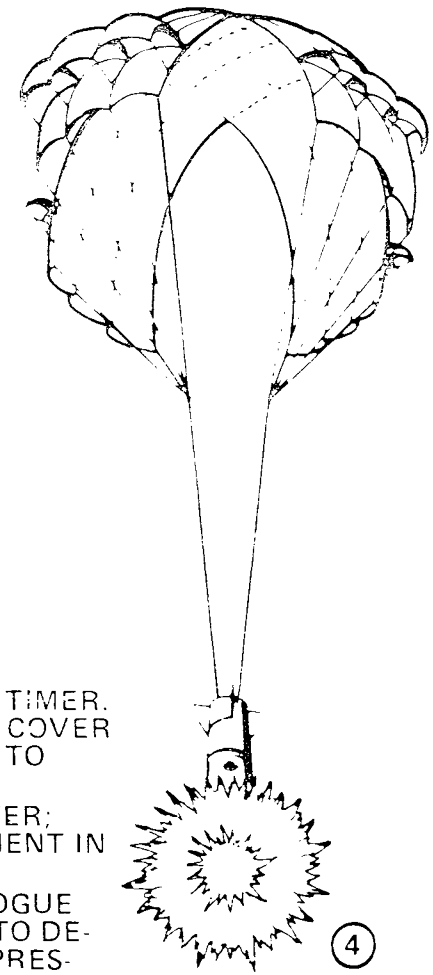


FIG A–15

ATTACK FLARE DEPLOYMENT SEQUENCE





(1) RELEASE OF FLARE FROM AIRCRAFT PULLS ARMING WIRE AND INITIATES PRESET TIMER. FLARE FREE FALLS TO DESIRED ALTITUDE (4,000 TO 5,000 FEET AGL). TIMER AND COVER RELEASE ARE EJECTED BY SPRING. TIMER PULLS OUT DROGUE CHUTE ATTACHED TO FLARE BULKHEAD.

(2) DROGUE CHUTE OPENING SHOCK INITIATES 5 SECOND DELAY, REEFING LINE CUTTER; TIMER AND COVER BREAKAWAY. FLARE DECELERATES TO MAIN CHUTE DEPLOYMENT IN 5 SECONDS.

(3) REEFING LINE CUTTER FIRES AND SEVERS LINE, RELEASING DROGUE CHUTE. DROGUE PULLS OUT MAIN CHUTE AND BAG, THEN PULLS BAG OFF ALLOWING MAIN CHUTE TO DEPLOY. OPENING SHOCK OF MAIN CHUTE ACTUATES FLARE IGNITION. NOSE CONE PRESSURIZES AND OPENS RELIEF PORTS.

(4) BURNING CANDLE CONSUMES NOSE CONE AND FLARE CASE. STRONGBACK REMAINS ATTACHED TO FLARE. EXPLOSIVE BOLT IS INITIATED 20 SECONDS BEFORE CANDLE BURNOUT AND MAIN CHUTE DUMPS. DEBRIS FALLS RAPIDLY TO EARTH.

FIG A–16

7. MLU–32A/B99 AIRCRAFT FLARE

a. Description. The MLU–32A Aircraft Flare (Fig A–17) is 63 inches long, 8.38 inches in diameter and weighs 147 pounds. The flare consists of an outer case and hardback assembly, a timer assembly, a balloon, a heat generator and the flare's candle. The outer case and hardback assembly consists of a cylindrical container and a tapered nose section, both made of 0.07 inch aluminum. A strongback is bonded with epoxy to the container and further secured to it by two steel straps. Two fixed suspension lugs, spaced 14 inches apart, are installed in the strongback. This item is only capable of being launched from standard 14 inch aircraft bomb racks mounted externally. There are no internal or external aircraft dispensers that will hold the MLU–32A Aircraft Flare.

Located at the forward end of the strongback, the timer assembly can be set at 2 seconds, 5 seconds and then at 5 second intervals up to 25 seconds. The timer's arming wire is routed through a retainer guide, which is attached to the strongback, and then inserted in the timer. A streamer assembly, which is a safety device that is removed before flight, is installed in both the timer and the nose cone's clamp. Internally, the timer assembly consists of a mechanical timer, a striker assembly, a stab primer and an initiation charge.

The balloon assembly consists of the balloon itself, a drag parachute, a cloth deployment bag and a "Y"–bridle. The balloon assembly and its heat generator constitute the suspension system for this flare.

Contained within the cylindrical container is the candle assembly. Its composition is of the magnesium, sodium nitrate and binder type. The candle also provides for 30 seconds of emitting a red light at the termination of candle burning. There is a descent system which deflates the balloon at candle burnout.

b. Functioning (Fig A–18). Ejection of the flare pulls the arming wire from the timer, which will then function after the preset delay has run out. The timer initiates a shaped charge that severs the nose cone clamp. The nose cone is then spring-ejected, releasing the drogue parachute. Upon opening, the drogue parachute, actuates the line cutter and initiates the pyrotechnic delay train of the vent and self destruct system. After approximately 3 seconds, a cloth deployment bag is stripped off of the balloon. The balloon deploys and is filled with ram air through its perimeter inflation ports. The "Y"–bridle is pulled taut by the balloon expansion and mechanically actuates the candle igniter. The candle ignition system simultaneously ignites the heat generator and the candle. The candle quickly burns through the fuzeable joint, tips over, and falls downward until it is suspended approximately 20 feet below the balloon by the energy-absorbing cable. The hot gases from the heat generator quickly arrest the balloons descent. After the candle burns for approximately 4 minutes, the vent functions to control the descent rate. This is necessary to release the buildup of hot gasses in the balloon, which would otherwise cause the flare to rise. Thirty seconds prior to burnout, the candle light turns red. The emitted red light acts as a burnout warning to those utilizing the flare. At this point, the self-destruct system cuts the balloon top, which completely deflates the balloon and allows the flare remnants to descend rapidly to the ground.

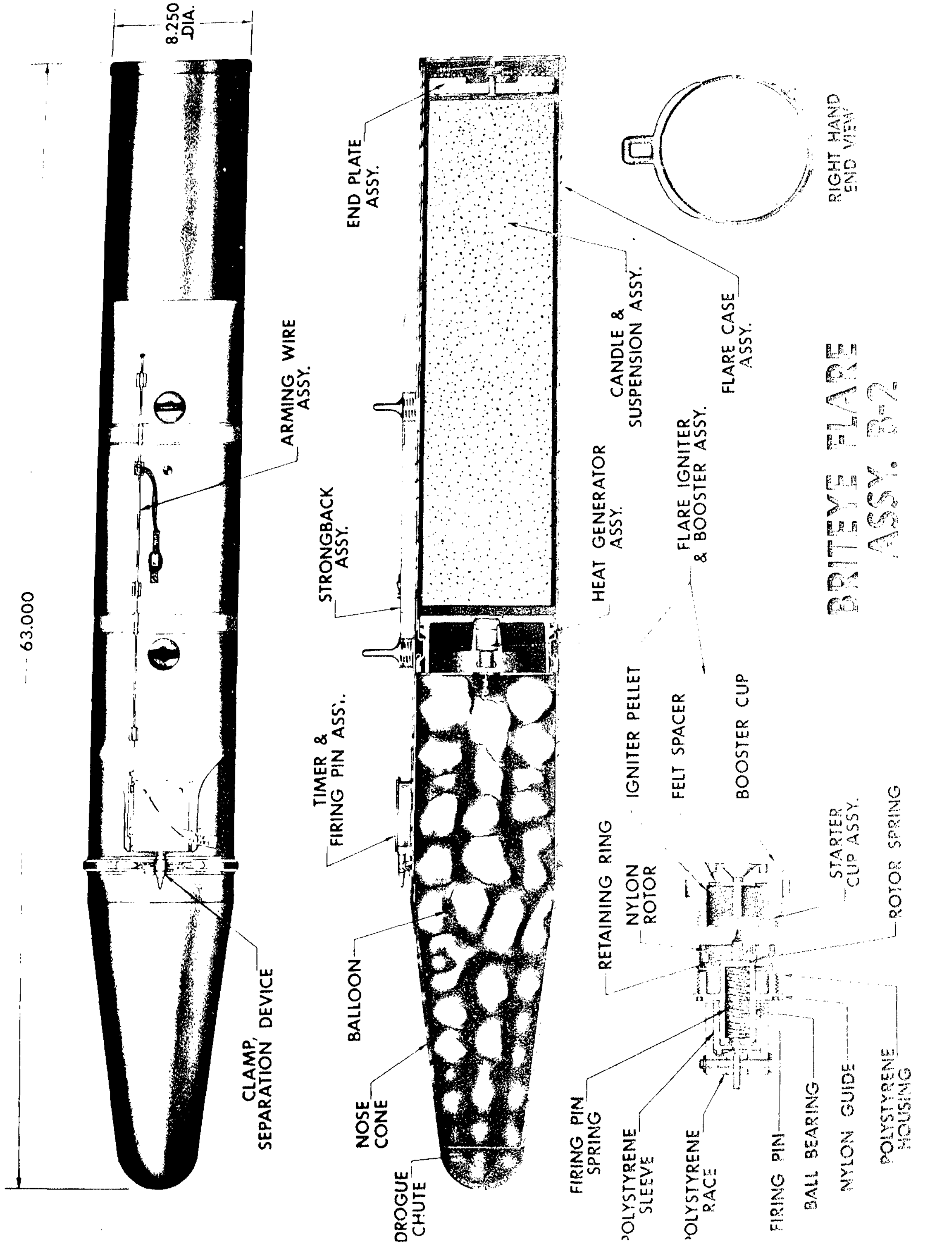

8.250 DIA.
63.000
ARMING WIRE ASSY.
CLAMP, SEPARATION DEVICE
END PLATE ASSY.
STRONGBACK ASSY.
TIMER & FIRING PIN ASSY.
BALLOON
NOSE CONE
DROGUE CHUTE
CANDLE & SUSPENSION ASSY.
FLARE CASE ASSY.
HEAT GENERATOR ASSY.
FLARE IGNITER & BOOSTER ASSY.
IGNITER PELLET
FELT SPACER
BOOSTER CUP
RETAINING RING
NYLON ROTOR
STARTER CUP ASSY.
ROTOR SPRING
FIRING PIN SPRING
POLYSTYRENE SLEEVE
POLYSTYRENE RACE
FIRING PIN
BALL BEARING
NYLON GUIDE
POLYSTYRENE HOUSING
RIGHT HAND END VIEW
BRITEYE FLARE ASSY. B-2

FIG A-17

FIG A–18

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APPENDIX B

FLARE QUESTIONNAIRE

A. Pilots Questionnaire: All pilots did not answer every question; therefore, the total number of responses to some questions may appear incorrect. Eighteen strike pilots completed this questionnaire.

LUU–2/B FLARE QUESTIONNAIRE

The purpose of this questionnaire is to determine which flare (MK–24 or LUU–2/B) is most effective for night strike operations. Your answers may have a direct impact on which flare will be bought for Fiscal Year 71, so please consider each question carefully. The timer mechanisms in the flares are different; however, an attempt will be made to ignite the flares over the target with the same burnout altitudes so that your comparison will be more valid.

(Circle the Appropriate Answer)

1. (Q) Which flare best enabled you to locate and attack the target on the first pass?

   LUU–2/B—3

   MK–24—9

   No Difference—6

2. (Q) Did you observe any glare from either the LUU–2/B or MK–24?

   Yes—11

   No—7

   If yes, which flare?

   MK–24—6

   LUU–2/B—0

   Both—5

   If yes, did the glare affect your ability to locate and attack the target?

   Yes—2

   No—9

3. (Q) If weather conditions such as haze, smoke, fog, or light rain (Circle those applicable) were present,

   Haze—3

   Smoke—4

   Both—5

   None—6

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which flare provided the best illumination?

MK-24—5

LUU-2/B—4

No Difference—3

4. (Q) Did you observe flickering of the light from either the LUU-2/B or MK-24 flare?

Yes—8

No—10

If yes, which flare?

MK-24—5

LUU-2/B—2

Both—1

If yes, did the flickering affect your ability to locate and attack the target?

Major effect—0

Minor effect—1

No effect—7

5. (Q) The LUU-2/B flare burns approximately two minutes longer than the MK-24 flare. Did this additional burn time improve your ability to conduct a greater number of effective passes against the target?

Yes—14

No—4

6. (Q) How do you rate the LUU-2/B burn duration?

Adequate—12

Inadequate—0

More than adequate—6

If inadequate, indicate the recommended burn time which you believe would improve the attack mission. __________ minutes.

Not applicable

7. At the end of full flare burning time, the LUU-2/B flare parachute is dumped, causing the burned-out flare to fall to the ground. (Q) Compared to the MK-24 flare which does not spill its parachute, how do you rate the dump feature of the LUU-2/B flare?

Desirable—13

Undesirable—2

Not observed—3

If undesirable, explain what effect this feature would have on the mission. ____________

Two pilots felt that they could not work under a flare if they didn't know when it would dump. It is not standard practice, however, for strike aircraft to fly under flares, because of the danger of presenting a good target to ground fire.

8. (Q) Which flare do you consider most effective for night strike operations?

MK–24—4

LUU–2/B—4

Both are equally effective—9

Not enough observed—1

9. Additional comments: (Be specific in your remarks about the LUU–2/B flare, as to recommended operational improvements or existing deficiencies of those flares which you observed).

a. A common comment was that the LUU–2/B "seems to flatten out the terrain features. Vertical development is not as noticeable as with the MK–24."

b. Several pilots said that the wind carried the LUU–2/B away from the target before burn-out, wasting the longer burn.

c. Several pilots found that they liked the LUU–2/B flare better as they gained experience with it.

10. Type Aircraft Crew Position SEA Tour Flare Operations Experience

The pilots responding flew A–1, OV–10, T–28, and A–37 aircraft. Fourteen of these pilots and copilots had SEA experience. Four had completed two tours. Thirteen had flare operations experience.

B. Flare Handlers Questionnaire:

LUU–2/B FLARE QUESTIONNAIRE

The purpose of this questionnaire is to examine the flare loading and handling, timer setting, and launch characteristics of the LUU–2/B flare. Your answers will have a direct effect on which flare will be bought for Fiscal Year 71, so please consider each question carefully.

Flare Description:

LUU–2/B. The LUU–2/B flare requires no mechanical safety devices. A 12 lb. pull on the lanyard removes the timer knob, permitting the timer to run down and to actuate the spring-loaded release mechanism. The released timer assembly serves as a drogue to pull the main parachute from its container. The opening shock of the parachute exerts 50 ± 10 lb. of pull on the igniter lanyard which activates the firing pin. This pin starts the flare candle ignition. If the flare time mechanism is actuated during in-flight (flareship) operations, it will not directly initiate the candle. The parachute lines may be tied or taped to the candle to prevent pulling of the igniter lanyard. The flare can then be safely jettisoned.

MK–24 Mod ¾. The MK–24 has a weather cap to protect the fuzes, a thumb screw to lock the fuze dials, and a safety cotter pin through the ignition dial to prevent accidental lanyard pull. The ejection fuze will dud if fired with the dial on SAFE. The ignition fuze will dud if both ejection and ignition dials are on SAFE. With the safety devices removed and neither fuze on SAFE, a 12 lb. lanyard pull will actuate the ejection fuze. This fuze fires an explosive charge to expel the ignition fuze, flare candle and parachute from the outer container.

(Circle the Appropriate Answer)

1. (Q) Do you consider the safety aspects of the LUU–2/B flare adequate for loading, handling, timer setting, and launch?

Yes—7

No—1

If no, indicate reason. Safety pin should be added.

How do you rate the overall safety of the LUU–2/B compared to the MK–24 flare?

Same—0

Better—8

Worse—0

2. (Q) Were the LUU–2/B timer markings easily read for accurate setting?*

Yes—8

No—0

How did the LUU–2/B timer markings compare to the MK–24 markings?

Same—0

Better—8

Worse—0

3. (Q) Do you consider the addition of a lanyard cotter pin necessary to prevent inadvertent timer actuation during the LUU-2/B handling and loading?

Yes—2

No—6

4. Please make specific, detailed comments on deficiencies noted and your recommendations for improvement.

One flare handler commented that the drogue strip made recovery of the lanyard a little difficult after manual launch from the "Raingutter."

*The white paint for the timer dial markings was missing from several flares, but the markings could still be read with the use of a flashlight. The use of a flashlight is standard when setting MK-24 flares, but is made easier with the LUU-2/B because the settings are much easier to make. The white paint is desirable, however.


FS
FLARE SAFETY MONTHLY
WAIT!
BEFORE YOU SLAP THAT FLARE!
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FLARE
SAFETY
STARTS WITH
YOU!


FLARES ROCKET
OUT OF THEIR TUBE...
...AT SPEEDS IN EXCESS OF 100 MILES PER HOUR....
GENERATING TEMPERATURES UP TO 1,000 DEGREES FAHRENHEIT

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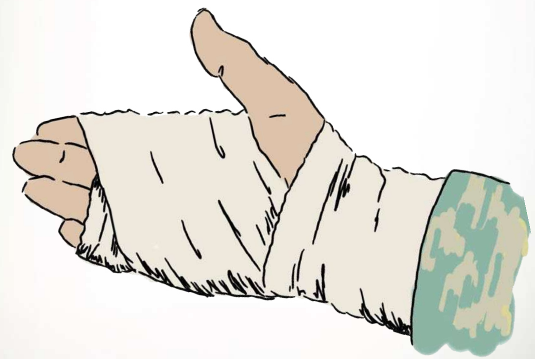
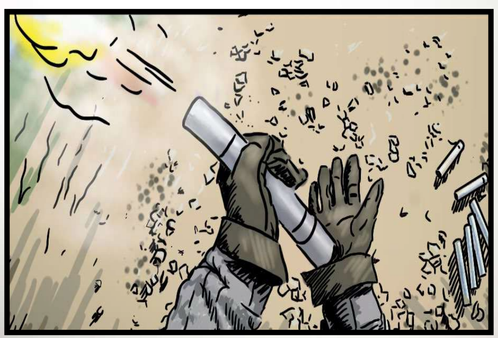
WHEN HANDLED SAFELY AND AIMED WITH PURPOSE, FLARES PROVIDE THE SOLDIER WITH A POTENT HAND HELD CAPABILITY THAT NO OTHER DEVICE CAN MATCH.

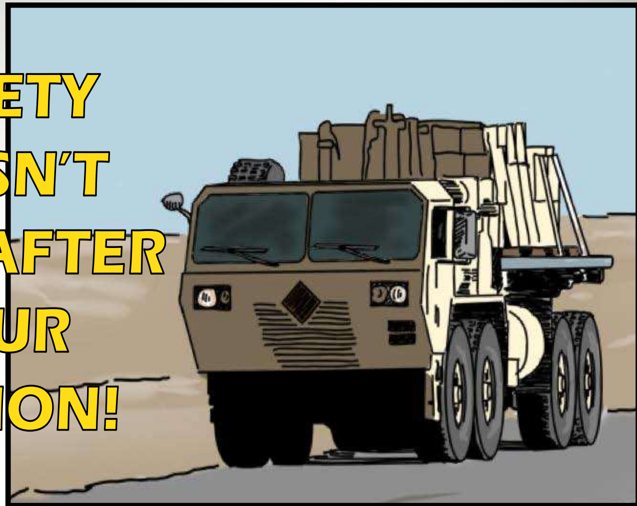
WHEN **MISHANDLED** HOWEVER, FLARES CAN AND HAVE INFLICTED DAMAGE THAT CAN BE DEVASTATING FAR BEYOND WHAT ONE MIGHT EXPECT FROM THIS SIMPLE DEVICE.





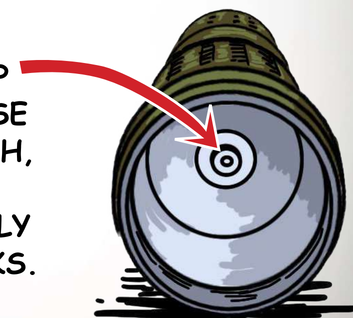

"MOST PEOPLE DON'T REALIZE THAT FLARES ARE PROJECTILES AND HAVE THE POSSIBILITY OF FIRING THEM AT YOUR FELLOW SOLDIER"
U.S. ARMY

SAFETY DOESN'T STOP AFTER YOUR MISSION!



UNUSED FLARES MUST BE REPACKED FOR RETURN TO STOCK AT A PROPER AMMO SUPPLY CENTER FOR FUTURE USE. THIS REPACKING PRESENTS YET ANOTHER OPPORTUNITY FOR ACCIDENTS.

INSERTING A FLARE IMPROPERLY, FIRE CAP SIDE DOWN, CAN CAUSE AN UNEXPECTED LAUNCH, INJURING NEARBY PERSONNEL OR POSSIBLY IGNITING AMMO STOCKS.




"WE'VE HAD A FEW INCIDENTS WHERE SOLDIERS LEFT THE STRIKER CAPS IN THE BOTTOM OF THE TUBES AND WHEN WE REPACKED IT THE FLARES GO OFF AND HIT THE CEILING AND CAUGHT OTHER THINGS ON FIRE"


THERE YOU HAVE IT. WHEN WORKING WITH FLARES,
BE SMART AND BE SAFE.
THIS BOOKLET WAS PREPARED FOR PMCCS BY
NEW EQUIPMENT TRAINING &
MEDIA PRODUCTION BRANCH,
PICATINNY ARSENAL, NJ.


PROJECT MANAGER
CLOSE COMBAT SYSTEMS

*FM 3-50

Field Manual
No. 3-50

Headquarters
Department of the Army
Washington, DC, 4 December 1990

Smoke Operations

DISTRIBUTION RESTRICTION: Approved for public release; distribution is unlimited.

* This publication supersedes FM 3-50, 25 July 1984.

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Change No. 1

Headquarters
Department of the Army
Washington, DC, 11 September 1996

Smoke Operations

1. Change FM 3-50, 4 December 1990, as follows:

Remove old pages:	**Insert new pages (attached)**
3 through 4	3 through 4
97 through 98	97 through 98
	54-A through 54-D

2. New or changed material is indicated by a

3. File this transmittal sheet in front of the publication.

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By Order of the Secretary of the Army:

DENNIS J. REIMER
General, United States Army
Chief of Staff

Official:

JOEL B. HUDSON
Administrative Assistant to the
Secretary of the Army
02289

DISTRIBUTION:

Active Army, Army National Guard, and U.S. Army Reserve: To be distributed in accordance with the initial distribution number 110743, requirements for FM 3-50.

Preface

Field Manual 3-50 provides US Army units with doctrine, tactics, techniques, and procedures to use smoke and obscurants to attack and defeat specific enemy targets, sensors, target acquisition systems, weapon guidance systems, and other enemy electro-optical devices. Also, it describes techniques to reduce friendly degradation in smoke.

The scope of this manual is smoke operations at the operational and tactical levels of war. The target audience is maneuver unit commanders and staff officers, particularly the G2/S2, G3/S3, FSO, and chemical officer at corps level and below. Most of the examples depict smoke support for brigade-level operations.

The focus is on synchronized smoke planning — smoke integrated into the commander's tactical plan, sustained as necessary to defeat the enemy's electro-optical systems and create a "one-way mirror" — one which our forces can both see and shoot through to set the terms of battle.

Smoke is a double-edged sword. Smoke conceals troop movements, slows attacking forces, disrupts command and control, and reduces the vulnerability of critical assets for both friendly and Threat forces. Combat operations in World War II and the Korean War demonstrated that the proper use of smoke enhances mission success and force survivability. In recent times, US forces have reinforced the positive benefits of large-area smoke use at the combat training centers at Fort Irwin, California; Fort Chaffee, Arkansas; and Hohenfels, Federal Republic of Germany.

In battle, the side that employs smoke correctly and is experienced in limited visibility operations will be more agile and respond faster to changing situations.

Users of this publication are encouraged to recommend additions, changes, or comments to this manual. Key your comments to the pages, paragraphs, and line(s) of text in which you recommend the changes. Provide reasons for each comment to ensure understanding and complete evaluation. Prepare your comments on DA Form 2028 (Recommended Changes to Publications and Blank Forms) and forward them directly to Commandant, US Army Chemical School, ATTN: ATZN-CM-NF, Fort McClellan, AL 36205-5020.

Unless this publication states otherwise, masculine nouns and pronouns do not refer exclusively to men.

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Contents

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Chapter 1

Introduction

Common sense tells us what can be seen can be hit and killed on the battlefield. The US Army uses smoke and obscurants to attack Threat reconnaissance, surveillance, and target acquisition (RSTA) efforts. It also uses smoke to protect the force and to support tactical deception operations. By combining obscuration with maneuver you can protect your force and deny the Threat the ability to acquire and engage it.

Historical Perspective

Armies have used smoke to confuse and deceive their enemies throughout history. We can find indications of smoke operations from as early as 2000 B.C. when the burning of damp straw was a common way to smoke enemy positions.

The War Department proposed the use of smoke to President Lincoln during the War Between the States. The idea was not taken seriously at the time and smoke was used sparingly. Documentation of the period reflected in the Cavalry Journal historical archives suggests that "...a little smoke, judiciously laid down, could have changed the entire course of history. Had the South used smoke, Federal forces may not have been able to stop Pickett's charge at Gettysburg even though the Federal force was greatly superior...."

The use of large-area smoke increased drastically during World War II. The British used smoke to effectively screen harbors, factories, and large cities in the United Kingdom from the Luftwaffe's relentless bombing. In 1943, US forces used smoke to protect the supply facilities and invasion fleet at Bizerte Harbor in North Africa from attacking German aircraft. The smoke blanket placed over this area by smoke generator units resulted in over 3,000 bombs falling harmlessly in and around the area.

The use of smoke and other manmade obscurants can give a commander an edge if applied properly. Natural obscurants can also be used to friendly advantage. The actions of Combat Command A (CCA), 4th Armored Division, during the Lorraine Campaign, in September 1944, demonstrated the use of fog as a combat multiplier.

On 13 September 1944, CCA forced a crossing of the Moselle River north of the heavily defended city of Nancy. On 14 September, CCA was ordered to bypass Chateau-Salins and exploit the weakness to the south. By 1900 hours, CCA began to draw into a perimeter defense around the town of Arracourt. This allowed the Germans to strengthen their position around Chateau-Salins and assemble forces for a major counterattack against the XII Corps right flank. The Fifth Panzer Army moved north, striking at CCA's exposed position around Arracourt. The ensuing battle was one of the largest armored engagements fought on the Western Front.

On the morning of 19 September, a heavy fog concealed the German movement, giving them tactical surprise and protection from Allied aircraft. Elements of the 133rd Panzer Brigade penetrated CCA's defenses. Two tank destroyer platoons and a medium tank company engaged the 133rd Panzer Brigade. The fog worked to the defender's (Allied forces) advantage, as the limited visibility negated the superior range of the German tank guns. As the fighting surged back and forth through the fog, CCA's tanks and tank destroyers used their mobility to outmaneuver and ambush the larger Panzers.

From 20 to 25 September, the Fifth Panzer Army directed the lllth Panzer Brigade and the llth Panzer Division into a series of attacks against the Arracourt position. Each assault followed the pattern set on 19 September. The Panzers attacked under the cover of morning fog, only to be thwarted by CCA's mobile defense and driven off by armored counterattacks of company or battalion strength.

The defensive actions fought around Arracourt stalled the German offensive. The 4th Armored Division claimed 281 German tanks destroyed, 3,000 Germans killed, and another 3,000 taken prisoner in the fighting. For the German offensive, the ground fog represented a double-edged sword. It provided

them concealment but ultimately led to their demise. For US forces, it proved to be a significant combat multiplier.

Description of Smoke and Obscurants

Obscurants are man-made or naturally occurring particles suspended in the air that block or weaken (attenuate) the transmission of a particular part or parts of the electromagnetic spectrum, such as visible light, infrared (IR), or microwaves. Fog, mist, dust, smoke, and chaff are examples of obscurants.

Smoke is an artificially created obscurant normally produced by burning or vaporizing some product. An example is the vaporization of fog oil to produce smoke from a mechanical smoke generator. We classify US and Threat smoke and obscurants, both currently fielded and developmental, as visual, bispectral, multispectral, or special-purpose obscurants. Visual obscurants defeat the visible through near IR portion of the spectrum; bispectral obscurants defeat the visible through far IR; multispectral obscurants defeat the visible through millimeter wave; and special purpose obscurants defeat specifically targeted portions of the electromagnetic spectrum.

Appendix G describes the characteristics of smokes and obscurants, how they work, and what obscurants are in the US inventory.

Uses of Smoke and Obscurants

We can render some electro-optical (EO) target acquisition and sighting devices ineffective; others we can degrade significantly; some we cannot affect at all. As a result of the development of IR and radar devices during World War II and subsequent technological advances, EO devices have supplemented conventional visual methods of target acquisition and aiming weapons. Precision-guided munitions and sophisticated sensors provide the ultimate in lethality on the battlefield: What can be seen can be hit and killed.

We use visual obscurants to defeat the enemy's battlefield viewers, such as binoculars, weapon sights, night observation sights, and laser range finders. We use bispectral obscurants to defeat the enemy's battlefield viewers and weapon guidance systems such as command line-of-sight or terminal homing systems on antitank and air defense missiles. When developed, we will use multispectral obscurants to defeat the enemy's battlefield viewers; weapon guidance systems; radar systems; and high-energy, microwave-directed energy weapons.

Table 1, on the next page, is a tactical decision aid for selecting the type of smoke to defeat a particular EO system. Detailed information concerning the types of smokes and obscurants and their effects on EO systems are in Appendixes G and B, respectively.

How and Where To Use Smoke

Smoke aids in deceiving the enemy, conceals maneuver, and increases your potential force-on-force ratio when your target acquisition systems can see through the smoke and the Threat's cannot (see Chapter 2). For smoke to do this, you must develop a plan to use smoke synchronized with your tactical plan.

Use the military decision model from FM 101-5 as general guidance for planning and executing smoke operations. Commanders must routinely give planning guidance to the staff that answers the following questions:

- What do I want smoke and obscurants to accomplish? (Degrade target acquisition? Conceal the movement of my main attack? Aid in deception?)
- Where and for how long am I willing to sustain this smoke cloud? (Over my own position? Between my unit and the enemy? On the enemy?)
- How much restriction in my own mobility can I accept? (Visibility 50 meters or less? More?)
- How much restriction in my own target acquisition and engagement capabilities can I accept? (If I deny another's laser designators, I also deny mine, but my thermal sights are unaffected).
- When might on-call hasty or deliberate smoke benefit me? (Where does my decision support tree indicate I may be exposed and need immediate smoke to obscure the enemy?)
- How will countersmoke help me? (If the enemy uses smoke, where and how should I retaliate with smoke to interfere with their synchronization?)

Categories of Smoke Operations

There are two general categories of smoke operations: hasty and deliberate.

Hasty Smoke Operations

Hasty smoke operations are smoke operations conducted with minimal prior planning. They are normally executed by the projected, on-board, and smoke generator units (company- and smaller-size elements) on hand at the time of the engagement. This does not mean that hasty smoke operations are not planned; rather, plan hasty operations as on-call smoke in your deliberate smoke plan. Use hasty smoke operations to support a combined arms force to counter an enemy action or anticipated enemy action of immediate concern to the commander. Hasty smoke operations generally cover a small area for a short duration.

Deliberate Smoke Operations

Deliberate smoke operations are conducted with detailed planning and are executed by either on-hand smoke assets or with those on hand augmented by corps and theater assets. Deliberate smoke operations normally are synchronized with specific times, events, or locations on the battlefield (for example, when we are within 1,500 meters of the objective, fire six battery volleys of 50-percent high-explosive and 50-percent smoke munitions onto the objective to obscure enemy observation). Deliberate smoke operations normally include multiple preplanned smoke operations. They cover large areas over long periods to support the operations of brigades, divisions, and corps.

Table 1. Electro-optical systems defeated by smoke.

Spectral Region	Electro-Optical System	Type of Smoke
Visible 0.40–0.75 mm	Viewers: –Daylight Sights –Naked Eye –Camera Lens –Binoculars/Standard Optics –Battlefield TV –CLOS Missiles (for example AT-3) –Night Sights	All
Near IR 0.75–4.00 mm	Viewers: –SACLOS Missiles (for example, AT-4 and AT-5) –Night Sights	All
	Sensors: –Laser Designators –Laser Range finders	All
Mid-IR 4–14 mm	Viewers: –Passive Thermal Sights	WP, PWP, RP, Type III IR Obscurant, Dust
Far-IR 14–100 mm	Sensors: –Thermal Imagers –Terminal Homing Missiles (AT-6)	WP, PWP, RP, Type III IR Obscurant, Dust
MM Wave and Lower Frequency 1.10 mm	Radar Radio Microwaves	WP and PWP (Instantaneous Interruption Only), Developmental Obscurants
X Ray and Higher Frequency	Directed EMP Nuclear Weapons	Oil Smoke (Attenuation Only), Developmental Obscurants

Smoke Planning

Each echelon of command plans for smoke employment to support both current and future operations. Integrate smoke into the overall tactical plan, synchronized with key events or decision points. Base smoke planning on the same factors as the tactical plan: mission, enemy situation, terrain, weather, troops available, time, and distance. Mission considerations include unit capabilities, detailed planning and preparation, employment techniques, communications, intelligence, and whether the unit has successfully operated in smoke previously.

The G3/S3 has primary staff responsibility for planning smoke operations in coordination with the fire support officer (FSO), G2/S2,

G4/S4, smoke unit commander, chemical staff officer, and staff weather personnel. When planning smoke operations, the primary focus must be to attack enemy EO systems and degrade enemy combat effectiveness without significantly degrading friendly command, control, or target acquisition capabilities.

Staff officers must constantly plan to integrate smoke into the tactical plans for both current and future operations. Planning ranges from deliberate plans to provide smoke support for future operations in a 48- to 72-hour window to hasty planning for current operations.

Staffs must develop estimates that define enemy capabilities and our own courses of action, analyze smoke targets, and prioritize smoke resources. They must finally recommend courses of action for the commander's approval. When the commander approves the staff estimates, the staff prepares orders that combine smoke with combat power. Appendix A shows a smoke estimate format and a smoke annex to plans and orders.

Situation and Target Development

Targeting begins with the commander's guidance and continues through the development of a prioritized list specifying what targets to attack and when to attack these targets (DECIDE) and acquiring high-payoff targets (DETECT) and what will defeat these targets (DELIVER). This process concludes with the commander's decision on which course of action he will select to engage the various targets: maneuver, fire support, and smoke unit support, or a combination thereof. There are two basic processes in the targeting process: situation development and target development.

Situation development and target development are the processes that provide commanders the intelligence and targeting data they need to plan and fight the close and deep operation. Both processes, conducted simultaneously, incorporate intelligence preparation of the battlefield (IPB) and the intelligence cycle functions. Situation development enables commanders to see and understand the battlefield in sufficient time and detail to employ their forces and weapons effectively. In situation development, the G2/S2 uses IPB to produce a description of enemy force disposition on the battlefield in terms of location, size, type, direction, rate of movement, and activity. For smoke planners, situation development provides information about weather, terrain, enemy disposition, and composition in the area of interest. FM 34-1 provides a more detailed description of situation development procedures.

IPB provides a basis for accomplishing situation and target development. IPB orients the mission planning, collecting, processing, and disseminating efforts of situation and target development. The IPB process includes—

- Threat evaluation. This is a detailed study of enemy forces and their composition, organization, tactical doctrine, weapons, equipment, and supporting battlefield functional systems. For smoke planning, we focus on enemy EO and smoke capabilities as listed in Chapter 2 and Appendix B.
- Evaluation of areas of interest and operation. This is a study of enemy order of battle (OB) for a specific area of the battlefield. For smoke planning, we focus on numbers and probable locations of EO systems.
- Terrain analysis. This is an analysis of the military aspects of the terrain in a specific area. For smoke planning, we focus on the terrain effects on smoke.
- Weather analysis. This is an analysis of the impact of weather on both terrain and friendly and enemy capabilities. For smoke planning, we focus on the weather effects on smoke.
- Threat integration. This is the development of situation, event, and decision support templates. For smoke planning we input the priority intelligence requirement (PIR) and extract actual findings from the decision support template.

Smoke Estimate Preparation

When the G2/S2 performs the IPB, the chemical officer, in coordination with the G3/S3, FSO, and smoke unit commander, will prepare the smoke estimate. This estimate will go to the G2/S2 and targeting officer for inclusion into the target value analysis (TVA) for fire support planning and to the G3/S3 and chemical staff for smoke target planning.

The chemical staff officer prepares a smoke estimate to recommend courses of action for attacking enemy targets with smoke and obscurants. Besides supporting the commander's estimate, the smoke estimate assists the chemical staff, FSO, and G3/S3 in determining the detailed plan for smoke employment. FM 101-5 contains detailed guidance on the military decision-making process and estimates.

Smoke Support Plan Development

Simultaneous with preparing the smoke estimate, the staff chemical officer develops a draft smoke support plan. The procedures for preparing a smoke support plan are—

- Coordinate with the commander and staff prior to smoke support planning. Obtain the restated mission.
  - Obtain required fire and smoke planning information such as task organization, smoke delivery systems, objectives, axis of advance or sector, and commander's intent.
  - Recommend smoke support coordinating measures such as key time, place, and event and no smoke

areas and target allocations (smoke unit targets, artillery targets, and mortar targets) based on available information such as restrictive fire line (RFL), coordinated fire line (CFL), no fire line (NFL), munition availability, and priority of fire.

- Update status displays.
  - Plot locations of maneuver elements and objectives.
  - Plot locations of agreed targets.
- Develop a smoke support plan.
  - Get target lists from the FSO.
  - Modify target lists as necessary. Use the smoke target analysis procedures in Appendix A as guidance.
  - Develop a list of smoke delivery assets.
  - Decide the type of support required (for example, smoke versus EO system effectiveness).
  - Decide the time support is required.
  - Decide the best delivery system to engage.
  - Decide the best delivery unit to engage (for example, smoke generator unit, direct support (DS), 155-battery).
  - Prepare and consolidate target lists.
  - Assign smoke target numbers. Appendix A outlines the procedure for numbering smoke targets.
- Coordinate the smoke support plan with the FSO.
  - Inform or brief requirements for fire support engagement with smoke.
  - Obtain target numbers for targets requiring fire support asset engagement.
  - Modify the plan as agreed.
  - Ensure the plan is logistically supportable and sustainable.
- Brief smoke support plan to obtain concurrence from the commander (or G3/S3 as required by local policy).
  - Brief requirements for fire support engagement with smoke.
  - Modify the plan as agreed.
  - Decide the support.
  - Decide the time.
  - Decide which smoke delivery unit (s) will engage.
  - Finalize the target list.
- Coordinate the fire support plan changes with the commander or G3/S3 and the FSO.
  - Inform or brief them concerning changes made in coordination.
  - Modify the plan as agreed.
- Coordinate the smoke support plan with adjacent units.
  - Inform or brief them concerning the plan.
  - Modify the plan if required.
- Confirm coordination with the commander or G3/S3 and with the FSO.
- Brief the smoke unit leader(s) on the smoke annex to the OPORD.

Smoke Support Plan Execution

The extreme impact of smoke on tactical operations mandates close coordination, control, and planning for contingencies. Command supervision and staff supervision are essential to ensure the use of smoke enhances rather than degrades mission success.

Commanders must control smoke in their area of operations. Use decision points based on IPB and human feedback to control when you start and stop smoke. Smoke unit leaders monitor the communications nets for the supported unit as well as internal nets. This ensures the commander has an immediate response to start or stop smoke at a particular point or time.

Plan to minimize friendly force degradation from our own use of smoke. Rehearse those contingencies. An antitank position with clear fields of fire may be valueless in dense smoke unless the gunner or section leader has rehearsed movement to previously prepared alternate positions (limited visibility positions).

The preceding paragraphs established the "Why" and "How" of smoke support. The remainder of Chapter 1 answers the "When and Where" and "What" and explains with what delivery systems and delivery units we make smoke. The remaining chapters outline Threat (Chapter 2) and provide doctrine, tactics, and techniques for smoke employment in the offense (Chapter 3), defense (Chapter 4), and other operations (Chapter 5). The manual concludes with smoke support sustainment planning considerations (Chapter 6).

Operational Concept for Smoke and Obscurants

Smoke and obscurants themselves are not lethal. However, when synchronized throughout the depth of the battlefield they enhance the maneuver commander's ability to maneuver. They concentrate combat power against enemy vulnerabilities at the critical time and place. They also reduce his own vulnerability to enemy intelligence and target acquisition. Smoke and obscurants provide the commander with another means to meet the imperatives of the AirLand battle by–

- Degrading the enemy's ability to see.
- Disrupting the enemy's ability to communicate.
- Concealing friendly forces.
- Deceiving the enemy.
- Providing a means to identify and signal.
- Degrading or defeating directed-energy weapons.
- Enhancing friendly weapon system effectiveness.

The Comprehensive Smoke Study analyzed what happened when US forces used smoke and the adversary used smoke, and the net effect on combat effectiveness when both sides used smoke and obscurants, The lessons learned indicate –

- Smoke favors the attacker. Our force exchange ratio improves 25 to 80 percent.

- Projected smoke is important to success, but resource intensive. Firing units require 400 percent above normal basic loads.
- Large-area smoke is beneficial. There is up to a 30-percent increase in our force exchange ratio. Combined with artillery-delivered WP smoke gives a 75-percent increase in our force exchange ratio.
- You should avoid smoke on friendly antitank guided missile lines of sight.

Operational Level of War

Operational objectives within a theater of war include the marshalling and sustaining of forces and materiel to conduct successful campaigns. Commanders and staffs at this level of war will plan and conduct smoke operations to—

- Deceive the enemy as to friendly force location, status, and movement.
- Defeat enemy air and satellite reconnaissance efforts.
- Reduce the effectiveness of enemy fire and air attacks.
- Defeat enemy precision-guided weapons.
- Increase force survivability.

Tactical Level of War

Obscurants can support the movement and positioning of forces on the battlefield and the provision of fire support. They can also conceal the logistical support of forces before, during, and after engagements with the enemy. The objective of smoke employment is to increase the effectiveness of US operations while reducing the vulnerability of US forces.

Obscurant use supports battlefield deception and enhances friendly combat operations by—

- Increasing friendly force survivability by—
  - Concealing friendly mass and maneuver.
  - Degrading Threat weapon system effectiveness.
  - Attenuating energy weapons.
  - Increasing friendly-to-enemy force ratio.
- Increasing Threat force vulnerability by —
  - Decreasing Threat rate of advance.
  - Disrupting Threat command and control.
  - Deceiving Threat intelligence collection.

In the offense, the commanders can achieve surprise and protect their force by combining obscurants with maneuver and firepower. Obscurants allow us to reduce our vulnerability through concealment as we mass forces to attack. Obscurants will conceal friendly movements and screen breaching of obstacles and river crossings. They will also negate the stand-off capabilities of enemy long-range antiarmor weapons and interfere with enemy guidance and acquisition systems. Smoke supports tactical objectives by deceiving the enemy as to the exact location, timing, and size of the main attack. It also isolates units for piecemeal destruction.

In the defense, obscurants support disruption of enemy activities and enhancement of friendly operations throughout the battlefield. Smoke will isolate attacking echelons and conceal friendly unit locations. It will screen friendly maneuvers, support deception, and interfere with enemy movement and communications. Obscurants help to preserve forces essential to the mission. Smoke supports tactical objectives by selectively denying air and ground routes and by forcing the enemy into tightened tactical formations, which are easier targets.

In a nuclear environment, temporary massing of friendly forces may create a particularly lucrative target. Dense smoke provides both concealment and some measure of protection against thermal radiation.

Commander and Staff Considerations

Commanders must be prepared to use smoke to their advantage regardless of whether it is employed by friendly or Threat forces. Commanders and staffs at all levels—

- Consider the use of smoke to enhance friendly scheme of maneuver.
- Avoid developing a predictable pattern of smoke use.
- Anticipate and plan to counter enemy smoke and countersmoke measures (see Chapter 2).
- Train for limited visibility operations to minimize friendly force degradation.

Operational Continuum

Smoke and obscurants disrupt the enemy's ability to locate, acquire, and defeat our forces across the operational continuum. Use smoke in peacetime, conflict, and war.

Peacetime

Use smoke in peacetime in support of security assistance operations, show of force, and peacekeeping operations. Smoke systems may be particularly useful in segregating or isolating violent elements. This creates a sense of isolation among the people. In counternarcotics operations, use smoke to restrict use of airfields and to conceal the movement of law enforcement personnel.

Conflict

Use smoke in conflict to support all types of military operations. Smoke is useful in insurgency/counterinsurgency and peacetime contingency operations in support of tactical objectives. Smoke systems may be particularly useful in concealing initial insertion of forces.

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This would provide surprise and security for our forces.

War

Use smoke in war to support all operational and tactical operations. Smoke is useful from the onset of hostilities to protect the force, alter force ratios, conceal maneuvering forces, and give leaders an added dimension of flexibility.

Spectrum of Conflict

The Army recognizes that under low-intensity conflict (LIC) conditions indirect, rather than direct, applications of military power are the most appropriate and cost-effective ways to achieve national goals. If US involvement requires military action, force protection and identification of Threat RSTA means are critical. In LIC, use projected, generated, and self-defense smoke to –

- Support counterinsurgency operations. Smoke use can protect the force in all phases of counterinsurgency operations. In addition, when identified we use smoke to attack Threat RSTA means. Smoke creates a psychological feeling of isolation. This may reduce the insurgent's will to resist.
- Support terrorism counteraction. Smoke use can restrict use of airfields or facilities and conceal the movements of counterterrorist forces. Use smoke to conceal objectives prior to assault or occupation by law enforcement or counterterrorist forces.
- Support peacekeeping operations. Smoke use can protect our forces by screening our forces from Threat observation. It can also restrict the effectiveness of combatant target acquisition or weapon guidance systems. Marking smokes are effective for signaling and early warning. In addition, we can use smoke and obscurants to segregate or isolate forces in conflict.
- Support peacetime contingency operations. Smoke use can protect our forces, particularly in a show of force or demonstration. In strikes, raids, and unconventional warfare, use smoke to attack known Threat RSTA means. For example, in a raid on a suspected Threat communications center, friendly forces would—

–Use projected smoke (for example, mortars, rifle grenades, or aviation-delivered smoke rockets) to obscure guard posts and observation points. This is particularly important when special operating forces are being inserted.

– Use emplaced smoke such as smoke hand grenades to conceal entry into the facility once their presence is known.

– Use projected or emplaced smoke to conceal their exfiltration route and allow them to break contact.

In high-intensity and mid-intensity conflicts, US forces face large, rapidly maneuvering formations on battlefields characterized by sophisticated weapons, high-consumption rates, and extended time and distance. Smoke supports all types of military operations in mid- and high-intensity conflict.

Using smoke and obscurants across the spectrum of conflict will positively influence the outcome of any operation. Chapters 3 through 5 outline tactics for smoke employment to meet the challenges of the spectrum of conflict.

The Battlefield

Smoke and obscurants disrupt enemy combat operations throughout the depth of the battlefield. One of the key concepts in AirLand battle is the entire battlefield consists of one single battle fought by one commander with one plan. Obscurant operations must support all levels of command in fighting a unified battle of deep, close, and rear operations.

Deep Operations

Deep operations disrupt the enemy's movement in-depth, destroy high-value targets behind the enemy's lines, and interrupt enemy command and control at key decision points. Deep attacks are conducted to create "windows of opportunity" by disrupting or destroying follow-on echelons. Smoke systems that support the deep battle include aviation, artillery, smoke generator, and armored vehicle smoke systems.

Army aviation assets deliver smoke rockets from attack helicopters to obscure enemy observation, degrade target acquisition, and mark targets for close air support aircraft. Medium-lift helicopters supporting airmobile operations can move chemical units with smoke generators behind enemy lines. In addition, we can air transport the chemical company of an airborne division to support airborne operations in the deep battle.

Current artillery-delivered obscurants will seldom have a direct impact on deep strike capability. In the far term, millimeter wave obscurants delivered by rockets onto radar sites will be effective to suppress enemy air defense and counterbattery abilities. Similarly, special purpose obscurants that block certain regions of the electromagnetic radiation will be more effective in disrupting hardened command and control centers than high-explosive munitions.

Deep attacks with armored columns may require the use of smoke self-protection systems. Combat vehicle defensive obscurant systems include vehicular launched grenades and vehicle engine exhaust systems. The prime constraints will be logistical support (fuel and armament).

Close Operations

In the defense a covering or screening force occupies a sector far enough forward of the forward edge of the battle area (FEBA) to prevent surprise, to force the enemy to deploy their forces, and to gain sufficient time to respond to the Threat. Extensive use of concealing and deception smoke helps to develop the situation by forcing the enemy to deploy. It also denies information about disposition and composition of friendly forces, degrading enemy target acquisition.

Defending forces fill valleys and terrain defiles with visual obscurants to force enemy helicopters above the obscurant cloud, while ground fire is adjusted, using thermal viewers. Use visual and infrared defeating smokes to support countersurveillance and counterreconnaissance.

Smoke provides concealment for maneuver and counterattack and reduces the effectiveness of enemy target acquisition. It also deceives the enemy about the true intentions of our forces and creates conditions necessary to surprise them. Smoke enables the covering force to delay the Threat advance more effectively.

When advanced positions can no longer be retained, the security force must quickly and efficiently conduct a passage of lines. It must hand the battle off to the main battle area (MBA) units. Smoke pots, smoke generator units, and projected smoke conceal friendly forces and routes during battle handoff.

Obscurants support the decisive battle in the MBA by concealing battle preparations, denying enemy intelligence information, and concealing maneuver and counterattack. Units conceal areas for real and decoy battle positions during initial preparation and camouflage. Before the battle, mobile units provide smoke in multiple areas until the battlefield is fully prepared.

Use smoke and obscurants aggressively to assist the unit in regaining the initiative. Obscurants isolate enemy echelons, conceal movement of counterattacking forces, and deceive the enemy about friendly intentions. Smoke from smoke units, smoke pots, and enemy smoke lines conceal movement of friendly forces. Artillery- and mortar-delivered smoke blinds enemy armored and antitank elements while friendly forces attack targets from the flanks using thermal viewers. Obscurants separate enemy echelons to preclude supporting and overmatching fire and to facilitate their piecemeal defeat.

Obscurants in the defense of the MBA require careful preparation to preclude an ill-conceived deception; disruption of friendly activities; or poorly-timed, low-visibility retrograde operations. Obscuration will slow friendly activities. Commanders and planners should plan additional time for movement under smoke and obscurants.

Rear Operations

Because support units normally remain fixed over a period of hours or more, smoke units will normally maintain a large-area haze over brigade and division support activities throughout the early part of the battle. Based on command priorities and resources, brigade and division support areas may be concealed by obscurants from the beginning to the end of the battle. Obscurants used in rear operations include deception and screening of vital targets. Such targets include communications centers, ammunition supply points, motor pools, tank parks, assembly and staging areas, and critical portions of main supply routes.

At the operational level, the protection of key transportation and logistics activities is critical to sustaining the force. Echelons above corps must plan for obscurants in the defense to conceal static operations. Ports and terminals; fixed rail facilities such as bridges, tunnels, and rail yards; logistics-over-the-shore sites; dams; locks; trailer transfer points; and critical points along main supply routes must be covered. Obscurants may also provide limited protection for nonstatic operations such as water transport, railroad operations, inland waterways movement, and convoys. Commanders and staffs must carefully plan operations to ensure that the use of friendly obscurants at one logistics facility does not impede activities at another.

Smoke can assist in defeating or delaying enemy airborne and airmobile operations. Place smoke over potential drop zones and landing zones in rear areas to conceal them and force the enemy aircraft to remain exposed to our air defense assets longer. This is particularly useful when you have significant intelligence indicators that airborne or airmobile operations are imminent, as smoke may deny the enemy the ability to insert those forces at all.

In the event of enemy breakthrough, freed sites and some rear area forces will not be able to maneuver away from an attacking Threat force. They will have to defend in place. Placing smoke on rear operations will conceal them from observation. However, this will degrade their operations. Smoke may be placed on the Threat forces, in coordination with electronic warfare and deception assets, to isolate the Threat units and prevent resupply, relief, or reinforcement prior to their destruction.

Battlefield Applications of Smoke

Smoke has four battlefield applications that support combat operations: obscuring, screening, protecting, and marking.

Obscuring Smoke

Obscuring smoke is smoke delivered directly on or immediately in front of enemy positions to blind or degrade their vision both within and beyond their location. Use obscuring smoke to attack and defeat enemy target acquisition and guidance systems at their source. Projected means, such as artillery, mortars, rockets, and rifle grenades, generally deliver obscuring smoke.

For example, smoke delivered on an enemy antitank guided missile (ATGM) position may prevent the system from acquiring or subsequently tracking targets, thereby reducing its effectiveness. Employment of obscuration smoke on an attacking armored force may cause it to vary its speed, inadvertently change its axis of advance, deploy prematurely, and rely on nonvisual means of command and control.

Screening Smoke

Screening smoke is smoke delivered in areas between friendly and enemy forces or in friendly operational areas to degrade enemy ground or aerial observation or both. It also defeats or degrades enemy EO systems. In general, use screening smoke to attack enemy target acquisition and guidance systems by placing smoke between the friendly unit and the sensors. Generated means, such as smoke generators, smoke pots, and smoke hand grenades, deliver screening smoke.

For example, employ screening smoke to conceal ground maneuver, breaching and recovery operations, key assembly areas, and supply routes. There are three visibility categories for screening smoke that the supported unit commander uses to establish the visibility requirement for a smoke mission. These are—

- **Smoke haze.** A smoke haze is a light concentration of smoke placed over friendly areas to restrict accurate enemy observation and fire. It is not dense enough to disrupt friendly operations within the screen. A smoke haze is defined as a concentration of smoke that would allow an individual to identify a small tactical vehicle between 50 and 150 meters away, but no farther than 150 meters.
- **Smoke blanket.** A smoke blanket is a dense, horizontal development of smoke used over friendly areas to conceal them from enemy ground and aerial observation. A smoke blanket may hamper operations of friendly troops by restricting movement and activity within the screen. It provides maximum concealment. It is a concentration of smoke that would allow the identification of a small tactical vehicle from 0 to 50 meters but no farther.
- **Smoke curtain.** A smoke curtain is a dense, vertical development of smoke. It is placed between friendly and enemy positions to prevent or degrade enemy ground observation of friendly positions. Since the smoke curtain is not placed directly on friendly troops, it will not hamper friendly operations. Commanders should use smoke curtains when friendly forces have air superiority or air parity. It does not prevent aerial observation; however, it may force aircraft to fly higher in order to see behind the curtain, thus increasing vulnerability to air defense weapons. In general, smoke curtains will defeat sensors in the visual through mid-infrared portions of the spectrum depending on the concentration of the smoke.

Protecting Smoke

Protecting smoke is smoke used to defeat enemy guidance systems or to attenuate energy weapons on the battlefield. Smoke and obscurants have the ability to reflect, refract, or absorb energy. When enemy gunners have already fired ATGMs or have used laser designators, use protecting smoke to immediately screen vehicle movements and defeat enemy guidance links. In an active nuclear environment or when threat of nuclear weapon use is high, use protecting smoke to attenuate the thermal energy from nuclear detonations.

When the enemy possesses directed-energy weapons, use smoke or obscurants to degrade the effects of those weapons. Directed-energy weapons include lasers; high-power microwaves; particle beams; and non-nuclear, directed electromagnetic pulse. A detailed description of the effects of smoke and obscurants on directed-energy weapons is in Appendix B.

Marking Smoke

Marking smoke includes smoke used to mark targets, identify friendly positions, and provide for prearranged battlefield communications. The smoke means used for identification or signaling smoke are normally projected means and smoke hand grenades. For example, use helicopter-delivered smoke rockets to mark a target for destruction by close air support aircraft, artillery, or mortars. Use smoke hand grenades to signal aircraft.

The primary factors that affect delivery of smoke onto a target are the smoke weapon system (delivery means and smoke agents) and terrain and weather conditions (steering winds and temperature gradients). Appendixes C and G detail smoke delivery means and smoke agents, respectively.

Smoke Delivery Systems

In general, there are three means for producing smoke: projected, self-defense, and generated smoke devices and systems.

Projected Smoke

Projected smoke is smoke produced by artillery or mortar munitions, naval gunfire, helicopter-delivered rockets, and bombs and generator smoke from fixed-wing aircraft. The advantage of using projected smoke munitions is you can place smoke directly on a deep, close, or rear target.

The disadvantage of projected smoke is that most projected smoke devices and munitions are lethal; they cannot be used on or near friendly forces. Most unit basic loads for munitions are insufficient for sustaining smoke on a target. The exception to this is generator smoke from fixed- and rotary-wing aircraft, which is considered a projected smoke system because of its ability to obscure deep targets.

Projected smoke can support both short- and long-duration missions based on the availability of ammunition. Combine use of projected smoke munitions with other smoke employment means throughout the battlefield.

The ideal battlefield applications for projected smoke systems are producing obscuring smoke, initiating screening smoke, and marking targets. For example, use projected smoke systems to place smoke on enemy intelligence gathering assets, ATGM positions, and artillery forward observers. Also, use them for initiating screening smoke forward of an attacking force that smoke generators will sustain.

Self-Defense Smoke

Self-defense smoke is smoke produced by smoke grenade launchers and the vehicle engine exhaust smoke system (VEESS), which we mount on most armored vehicles. An advantage of this system is rapid smoke production and responsiveness to the small unit leader. Disadvantages include danger to dismounted troops with the grenade launchers, interrupting your own target acquisition while taking evasive maneuvers, and additional fuel consumption for VEESS.

The ideal battlefield application for self-defense smoke devices is to conceal armored vehicle movements and to reduce vulnerability to attack by enemy antiarmor weapons. The devices function as follows:

- Armored vehicle smoke grenade launchers. Mounted on M88, M113, M60, Ml, M2, and M3 families of armored vehicles, smoke grenade launchers provide rapid obscurant production to assist the vehicle in self-defense. The launchers deliver the obscurant in front and/or to the flanks of a vehicle by smoke grenades electrically fired from the vehicle.
- Vehicle engine exhaust smoke system. The VEESS injects diesel fuel into the engine exhaust system. The fuel then vaporizes and is released into the air, where it condenses and produces smoke Vehicles that currently have the VEESS include the AVLB. LEV, M88A11, M60, Ml, M2, and M3 families of combat vehicles.

Generated Smoke

Generated smoke is smoke produced by smoke pots, smoke grenades, and smoke generators. Steering winds deliver generated smoke to a target. Combine generated smoke with projected smoke to provide depth of coverage throughout the battlefield. Generated smoke can cover small and large areas for up to an indefinite period of time based on the availability of logistical support, particularly fuel.

- Smoke pots and smoke grenades. You can pre-position these. They do not require an operator. You can ignite them manually or electrically. Use these smoke devices in hasty smoke operations because of their relatively short burn time and ease of access. The ideal battlefield applications for smoke pots are initiating screening smoke, marking smoke, and providing smoke unit self-protection. Smoke hand grenades are best for small-area screening smoke (squad-size maneuver) and marking smoke.
- Smoke generators. Smoke generator units produce large volumes of smoke to support hasty or deliberate smoke operations. Smoke generator units require a stand-off distance from the target based on wind speed and direction. Smoke generators are ideal for large-area smoke missions of long duration. They require detailed planning for logistical support. The ideal battlefield applications for smoke generators include screening, protecting, and sustaining obscuring smoke.

There are two concepts for employing smoke generators: mobile and stationary.

Mobile smoke is smoke produced while the system is on the move. Mobile smoke units normally are positioned well forward on the battlefield. They have the advantage of maneuver, but are exposed to more enemy weapon systems. They have a self-concealment ability that enhances their survival, and they can make smoke from a freed position or while moving. Mobile smoke systems rely heavily on passive operations security (OPSEC) measures to enhance their survivability.

Mobile smoke is supplied by units equipped with M1059 mechanized smoke carriers or motorized M157 smoke generators.

The M1059 is an M113 armored personnel carrier (APC) equipped with the M157 smoke generator set. This system can support armored and mechanized forces well forward. It is less vulnerable to small arms and indirect fire than wheeled systems due to its armored plating. Its tracked chassis provides it with the ability to move with its supported unit both on and off the road.

The motorized M157 smoke generator is an M1037 HMMWV equipped with an M157 smoke generator set. This system can provide mobile smoke to light infantry and specialized units. This system is vulnerable to small arms and indirect fire.

Stationary smoke is smoke produced from a fixed location, normally by units equipped with M3A4 mechanical pulse jet smoke generators mounted on M998 HMMWVs or M151 1/4-ton vehicles with trailers. Units move their vehicles and smoke generators into positions on a smoke line and then produce smoke. These units are limited by their mobility and require more time to set up and depart an area. They are well-suited for large-area smoke missions conducted in rear areas.

Weather and Terrain Effects

Steering winds actually carry the smoke and determine its direction, speed, and downwind travel distance. Temperature gradients are normally based on the time of day. Temperature gradients affect the height, density, duration, and travel distance of smoke. There are three types of temperature gradients: lapse, neutral, and inversion.

Since steering winds carry smoke, smoke usually follows the contours of the earth's surface. On flat, unbroken terrain and over water (open terrain), smoke streamers take longer to spread out and mix with other streamers. Obstructions, such as trees and buildings, tend to break up smoke streamers. The streamers may then re-form, cover a larger area, and create a more uniform cloud than over open terrain. Large hill masses and very rugged terrain cause strong cross currents of wind and tend to create holes and uneven dispersal of the smoke cloud.

Appendix F details the effects of weather and terrain on obscurants. It also gives a summary of the best and worst employment conditions.

Smoke Units

Smoke generator units are assigned to chemical battalions under chemical brigades at corps, to chemical battalions at TAACOMs, and to divisions. Detailed information concerning the modified or living tables of organization and equipment (MTOEs/LTOEs) and capabilities of these units is in Appendix D.

The platoon is the lowest echelon of command for smoke units that is self-sufficient. Table 2, below, outlines the smoke coverage capabilities of smoke platoons.

Tactics, Techniques, Procedures, and Unit Guidelines

Smoke tends to draw enemy attention and fire especially when used over friendly areas. The effect of enemy fire can be minimized by detailed planning, synchronizing all smoke assets with firepower, and limiting exposure of smoke assets to that fire.

Tactics, Techniques, and Procedures

The commander that "owns" the terrain is responsible for controlling the smoke. Place smoke before the enemy can pinpoint targets. Employ smoke during hours of darkness and limited visibility periods (rain, fog, ice fog, snow, sleet) to enhance its effectiveness. Synchronize all smoke assets for maximum impact

Table 2. Smoke platoon coverage capabilities.

	No. of Generators	No. of Point Sources	Average Cloud Parameters			
			Crosswind Width		Downwind Depth	
			Haze	Blanket	Haze	Blanket
Stationary Smoke	24	24	1.00–3.40 km	0.50–1.70 km	0.65–10.00 km	0.65–10.00 km
	24	12	0.50–1.70 km	0.30–0.90 km	0.65–10.00 km	0.65–10.00 km
	12	6	0.30–0.90 km	0.15–0.50 km	0.65–10.00 km	0.65–10.00 km
Mobile Smoke	12	6	0.55–1.40 km	0.50–1.20 km	0.15–3.60 km	0.05–1.40 km
	14	7	0.60–1.50 km	0.55–1.30 km	0.15–3.60 km	0.05–1.45 km

against the enemy. Coordinate smoke employment with adjacent units and all units in the operational area to minimize friendly unit degradation.

Understand that smoke compresses the battlefield by limiting visibility. Training soldiers to operate in smoke reduces the degradation caused by smoke. It also reduces psychological impact such as confusion, fear, and isolation on troops.

Smoke cloud size should be large enough to prevent the enemy from saturating the entire smoked area with fire. The target should be offset from center within the smoke. A rule of thumb is for the screen to be five times the size of the target. Avoid patterns for smoke employment. Avoid placing smoke over the center of your target every time. Maneuver using the flanks and edges of the smoke alternatively with the center.

To support tactical deception, employ smoke over other likely areas to dilute the volume of fire and draw attention to the areas of little or no importance. The smoke should approximate the principal smoke cloud in size. Establish and enforce mobile smoke control measures. The smoke control officer controls the smoke operation from a vantage point allowing target observation, ensuring it is completely concealed by smoke. When using self-defense smoke, ensure the entire squad, section, or platoon uses the smoke simultaneously to preclude drawing attention to a lone vehicle.

Start the smoke mission prior to operation start time and continue well beyond the end of the operation. For example, a river crossing is scheduled for the time from 0500 to 0700. Start smoke at 0400 and stop smoke at 0800 to confuse the enemy as to the exact crossing time and size of the force.

Limited visibility positions, preplanned and previously prepared, will minimize degradation caused by friendly or Threat use of smoke. Rehearsal of displacement under smoke will help you avoid confusion and disorientation and rapidly restore engagement capability.

Unit Guidelines

Smoke units are vulnerable to enemy direct fire weapons. Use the following guidelines when employing smoke generator units. Smoke units should, whenever possible, avoid prominent terrain features and locations that would permit accurate map firings or fire through adjustment from a known point.

Do not use mobile smoke vehicles to lead the attack. Use them to screen the flanks or main body maneuvering forces. Do not employ smoke units less than a platoon-size element. Use stationary smoke units to conceal rear area facilities and light infantry forces.

Command and Support

Smoke units operate under two types of relationships: command and support. A command relationship reflects the chain of command and degree of authority. A support relationship represents the manner in which the maneuver unit is to be supported.

In the tactical planning process the staff recommends the appropriate command or support relationship between the chemical unit and the supported unit. This relationship defines the specific responsibilities between supporting and supported units. Generally, smoke units at corps and division levels establish support rather than command relationships. Direct support (DS) is the preferred support relationship for company-size and larger chemical units. Attachment is the preferred command relationship for chemical platoons.

Organization and Principles

Smoke units work most efficiently under the control of a parent chemical unit. This organization permits close control and the most productive use of all assets. The commander continuously monitors the progress of assigned tasks. He shifts elements where the need is greatest throughout his area of operations. On the other hand the supported unit commander at the lowest level gets greater responsiveness when the chemical unit is under his direct control. He determines the task organization and gives missions directly to the units under him.

Providing smoke units in a command or a support relationship is a balance between the needs of the higher commander for flexibility and the needs of the subordinate commander for responsiveness. The corps may provide each committed heavy division with one motorized and one mechanized smoke company. Light infantry divisions are normally provided a dual-purpose smoke/decontamination company. Units are provided in either a command or support relationship.

For brigades already in contact or when contact is imminent, it is also appropriate for the division to allocate chemical units in an OPCON or attached status. Brigades, in turn, can provide chemical assets directly to their battalion task forces only when they receive the chemical assets from the division in a command relationship. Otherwise, the chemical unit commander deploys his subordinate elements based on his estimate.

At each echelon, commanders use organizational principles, derived from the AirLand battle imperatives, to guide the employment of chemical units. These principles include the following:

Task organize to meet requirements. Mission requirements drive size and composition of task forces. A mix of chemical units is often necessary to achieve the proper balance of capabilities.

- Task organize by platoons.
- Give priority to the main effort. There are not enough chemical assets on the battlefield to handle all

tasks. Chemical units are not spread evenly across the battlefield but are concentrated with the main effort to ensure its success.

- Integrate chemical support with maneuver and fire. The scheme of maneuver governs the use of smoke and reconnaissance assets.
- Do not hold smoke units in reserve. Smoke assets are too scarce and valuable to be held out of the fight. They must refit quickly and return to their primary mission.
- Make logistically sustainable plans. Resources are always limited. The availability of fuel and fog oil restricts chemical unit ability to execute smoke missions. Conduct detailed planning for chemical unit sustainment and supporting logistics.
- Maintain effective command and control. Effective plans use all available controlling headquarters and hand off operations smoothly between them.

Responsibilities

When supported by a smoke generator unit, both the maneuver unit commander and the smoke unit commander have specific sets of responsibilities for planning and coordinating the smoke mission. Smoke missions involve close coordination between the supported unit commander and staff and the smoke unit commander. Commanders must use the same troop-leading procedures for smoke assets as they will for their maneuver units, ensuring smoke unit commanders have adequate time and resources to plan and prepare for smoke support.

Maneuver Unit Commander's Responsibilities

The maneuver unit commander is responsible for the overall tactical operation. This commander must execute coordination with all units participating in or influenced by the smoke operation. He defines smoke support requirements to include—

- His intent.
- Visibility criteria within the smoke.
- Location and size of the smoke target.
- Time for effective smoke to be on the target.
- Duration of effective smoke on the target.
- Security of smoke assets.
- Immediate support available for the mission.
- Preparation of a smoke annex for the operation.

Smoke Unit Commander's Responsibilities

When the smoke plan calls for support from a smoke generator unit, the commander of the smoke unit is responsible for all activities concerning establishing and maintaining smoke on the designated target. Based upon information from the maneuver commander, the smoke unit commander performs the following tasks:

- Plans for map, air, or ground reconnaissance.
- Coordinates the mission with supported and adjacent units.
- Selects and coordinates smoke lanes (mobile smoke) or smoke lines (stationary smoke).
- Coordinates communications nets.
- Provides input for the smoke annex.
- Identifies additional support requirements within the limitations of command or support relationships.

Chemical Staff Officer's Responsibilities

The chemical staff officer plans and monitors the execution of the smoke plan, in coordination with the FSO and smoke unit commander. The procedures for smoke planning have been discussed. The procedures for monitoring execution are—

- Direct the chemical staff in monitoring the smoke support plan.
- Monitor planned smoke engagement by fire support assets:
  - Coordinate with FScell.
  - Determine whether planned fire was executed.
  - Make changes as necessary.
  - Report changes as required.
  - Update status displays.
- Monitor planned smoke engagement by smoke unit assets:
  - Monitor the smoke unit net.
  - Determine success (Smoke on target on time? Did it achieve purpose?).
  - Make changes as necessary.
  - Report changes as required.
  - Update status displays.
- Monitor planned smoke employment by maneuver units (for example, VEESS and smoke pots):
  - Monitor the appropriate command or maneuver unit net.
  - Determine success (Smoke on target on time? Did it achieve purpose?).
  - Make changes as necessary.
  - Report changes as required.
  - Update status displays.
- Monitor immediate calls for smoke:
  - Monitor the appropriate net (FScell and smoke unit).
  - Determine if smoke support is required.
  - Determine the best asset to engage. (Note: Fire support assets have the quickest response time.)
  - Respond if necessary to coordinate smoke support from other than fire support assets.
  - Update status displays.

Chapter 2

Threat

US forces may have to fight enemies ranging from sophisticated armored forces of Warsaw Pact and the more advanced emerging countries to unconventional forces of the Third World. The reconnaissance, surveillance, and target acquisition (RSTA) capabilities of our potential adversaries range from binoculars and night vision devices to laser and thermal imaging systems. We must focus our training, doctrine, and tactics in smoke and obscurants on degrading and potentially defeating these types of systems.

The training begins with identifying the location, types, capabilities, and employment procedures of enemy systems on the battlefield. The FM 100-2 series covers the Soviet Army and North Korean Army. The Cuban Forces Handbook, DDB-2680-62-86, dated May 1980 and similar handbooks for other countries are excellent sources of information on Third World countries. These are excellent references for unit organization and equipment, operations and tactics, and specialized warfare.

The smoke capability of our potential adversaries ranges from field expedient methods to extensive smoke-producing equipment and organizations in the field. Clearly the most significant Threat smoke capability resides within the Soviet Union. Their continued emphasis on adapting existing smoke assets to tactical missions and the development of new smoke systems allows Soviets to employ smoke in depth and in large areas for extended periods.

Historically, the Soviets relied heavily on smoke. In many instances smoke use was directly responsible for operational success. One Soviet writing states that during an offensive action smoke screens can reduce their losses of combat vehicles by 60 percent to 80 percent. In World War II, the Soviets established smoke lines up to 100 kilometers long, maintaining them for several days, weeks, and months.

The Soviets state that smoke carries more importance today than in World War II. This is due to the growth of highly sophisticated, long-range target acquisition systems that relatively inexpensive smoke and obscurants can defeat. They believe that smoke and obscurants can degrade and potentially defeat the use of optical, laser, night vision, and even thermal imaging systems. For this reason the Soviets plan that they will use smoke whenever and wherever the tactical situation permits.

For these reasons, our intelligence preparation of the battlefield (IPB) must include both Threat RSTA and smoke capabilities. This chapter outlines Threat RSTA and smoke employment doctrine. Chapters 3 through 5 outline doctrine and tactics to attack Threat RSTA efforts and protect the force.

Reconnaissance, Surveillance, and Target Acquisition

The effective employment of battlefield smoke and obscurants requires an understanding of Threat RSTA capabilities and how these capabilities support Threat operations. The Soviets define reconnaissance as the collection of intelligence information about the location, disposition, composition, number, armament, combat preparedness, character of activities, and intentions of the enemy in the interests of combat.

Threat RSTA encompasses all methods, such as photographic intelligence (PHOTINT), imagery intelligence (IMINT), and human intelligence (HUMINT). The most reliable methods and therefore the most used methods of RSTA are also easily defeated by smoke and obscurants. The Threat groups these methods into three major areas (aerial, ground, and artillery) that encompass the strategic, operational, and tactical depth of the battlefield.

Aerial reconnaissance sources are the satellites, front/army aviation assets, rotary-wing aircraft, and remotely piloted vehicles (RPVs).

Ground reconnaissance includes long-range reconnaissance units of front/army and divisional organizations and special reconnaissance, such as NBC, engineer, and medical reconnaissance.

Artillery reconnaissance uses artillery observation posts through direct observation, supplemented by radar, sound, and flash ranging, and

information resulting from electronic means.

Threat forces will conduct reconnaissance to acquire information on US nuclear weapons, force disposition, and intentions. In the Soviet ground forces, dedicated reconnaissance units will conduct aggressive RSTA for commanders from the front down to regiment.

Aerial Reconnaissance

Satellite, or "cosmic" reconnaissance, includes photography and television. It is controlled by the GRU (general staff's main intelligence directorate). One reconnaissance satellite version contains a video system on which images are stored and later retransmitted to Soviet ground stations.

Aerial reconnaissance is the principal method of gathering target intelligence. It provides the most timely and reliable information on the character and location of targets, particularly those in the enemy rear. Aerial reconnaissance recognizes four major categories of targets:

- Nuclear weapon systems and storage depots.
- Active and potential airfields.
- Defensive positions and systems (AD, C3, EW).
- Reserves, logistic facilities, and approaches.

Front air forces normally include an air reconnaissance regiment, but may have as many as three. These regiments are self-contained and process the information they collect. There are 24 to 40 aircraft per regiment. Their collection capabilities include fixed-frame and strip photography, infrared (IR) photography, television, and side-looking airborne radar (SLAR). An example is the FOXBAT B, which carries five nose-mounted cameras and IR linescan equipment. It provides a coverage corridor of up to 70 kilometers. The aerial television with down-link does not give the resolution of still photography, but it is near-real time. About half of the Soviet reconnaissance aircraft

can transmit their information inflight. High-performance aircraft and helicopters can be equipped with laser range finders and designators.

Reconnaissance aircraft fly at a high speed and low altitude, out to 600 kilometers beyond the forward edge of the battle area (FEBA). However, certain reconnaissance aircraft, such as the FOXBAT B (with visual and IR cameras) and the FOXBAT D (with SLAR), may perform their missions at high altitude without having to cross their forward line of own troops (FLOT).

Front and army RSTA assets may include a squadron of drones, commonly the DR3. Drones may have vertical and side-looking cameras, using visual and IR film. A drone may also carry a video with real-time down-link, though this would reduce its range. One drone squadron could launch 20 missions a day.

Aerial reconnaissance is particularly critical to the initial air operation. Predesignated strikes are planned in detail. Maps and terrain models are used to familiarize pilots, plan approach and departure routes, and determine attack techniques and routes. The vulnerability of high-performance aircraft to ground-based air defense necessitates a low-altitude (ideally, 50 to 100 meters), high-speed approach in minimum time. The pilot has three to six seconds to identify his target. Helicopter squadrons at army and division level will fly missions in support of engineer, chemical, and artillery reconnaissance.

Ground Reconnaissance

Reconnaissance units are assigned to all echelons of the Soviet force structure, from regiment to front. Reconnaissance units are equipped with tanks, BMPs, BTRs, and BRDM2 scout cars, and reconnaissance variants of each. Specialized vehicles perform engineer and NBC reconnaissance.

The BRM is a BMP variant mounting the TALL MIKE ground surveillance radar. Some units will have the PSNR (portable information gathering station), a man-pack radar, or a mixture of both. Detailed information on the reconnaissance units' organization and equipment can be found in FM 100-2-3.

Ground reconnaissance is primarily the concern of the tactical commander at division and below. His or her interest is the enemy and terrain to the immediate front, out to 100 to 150 kilometers. Tactical ground reconnaissance units operate out to 50 kilometers in front of the division. Airborne reconnaissance teams can operate out to 100 kilometers.

The information gathered directly supports the plan of fire and maneuver. Reconnaissance units will operate as patrols of two to three vehicles. The greatest effort will be directed toward suspected enemy strength and primary axes of advance. These patrols will avoid combat if possible. They will concentrate their efforts on finding enemy units, determining their strength, disposition, and weapons. As the battle is joined, these patrols will attempt to penetrate the FEBA to report on rear area activities, movement of reserves, and location of supply routes.

In addition to dedicated reconnaissance units, the organization of the regiment in march maximizes reconnaissance. To maintain the momentum of the attack, the regiment in march allocates its combat power forward in increments of one-third. This march formation assures that the main body is not impeded by a small enemy force.

The first element is the combat reconnaissance patrol (CRP), consisting of a reinforced platoon. Engineer and NBC reconnaissance assets usually will be attached to the CRP. The CRP engages enemy units to determine strength and disposition. If the CRP cannot overcome the enemy, it will attempt to

fix the enemy in place to facilitate the employment of its parent, the forward security element (FSE), consisting of a reinforced company. Next follows the advance guard, a reinforced battalion.

Target acquisition for direct fire begins early in the battle. A PRP3, with its SMALL FRED target acquisition radar, will be found with the advance guard, if not sooner.

Most Soviet combat vehicles carry active IR for night vision and fire control; many are equipped with laser range finders. Laser range finders in vehicles and artillery units are usually Nd: YAG (Neodymium: yttrium aluminum garnett) operating in the visible spectrum at 1.06 microns. Some Third World countries are capable of and have installed thermal imagers rather than active IR optics on their combat vehicles fleetwide. This capability increases the Threat, because reconnaissance and combat units will be able to detect and engage friendly units using these devices.

Artillery Reconnaissance

A network of observation posts controls artillery fire. Artillery observation posts locate targets and reference points. They transmit the data back to the firing batteries and adjust fire. Some observation posts will be located with the advance maneuver elements. Armored command and reconnaissance vehicles (ACRVs) (which function as fire direction centers as well as observation posts) carry day/night observation devices and laser range finders for target acquisition, topographic survey equipment for location data, and a fire direction computer.

Battlefield surveillance radars also support target acquisition and fire adjustment. The PRP3 mobile observation, a BMP variant, is found in each howitzer battalion. It carries the observation devices of the ACRV and the SMALL FRED radar, which detects targets and adjusts fire out to 20 kilometers. The BIG FRED battlefield surveillance radar, mounted on an MTLB, a light transport combat vehicle, is found in the target acquisition battery of the artillery regiment. The MI2 HOPLITE from the division helicopter squadron is also used for target acquisition and fire adjustment.

Combined Arms Operations

The Soviets believe the tank to be the keystone of the combined arms operation. Their concern about NATO antitank capabilities gives them great incentive to develop both improved and more extensive obscuration capabilities and tactics. Soviet writings often cite the Arab-Israeli War of 1973, in which ATGMs destroyed over one-third of Israeli armored vehicles in one week. Their doctrine reflects this concern over defeating enemy antitank weapon systems.

Threat Smoke Tactics, Techniques, and Procedures

In addition to the three battlefield smoke applications, we can expect the Threat to follow several guidelines when using smoke. These include the following:

- Cover an area five times the size of the target, with the target off center within the smoke.
- Light dummy fires or use flares within the smoke to give the false impression of a hit when enemy fire falls within the smoke.
- Initiate the smoke two to three hours before starting the operation; sustain the smoke along a wide front to conceal river crossing operations.
- Place smoke on both sides of the river during crossing operations.
- Make maximum use of floating smoke pots and smoke barrels to cover the crossings.
- Use decoy smoke at one or more likely crossing sites in an attempt to deceive our forces.
- Use smoke to conceal aerial reference points.
- Use smoke to conceal important locations and possible targets such as troop concentrations, crossing sites, bridges, railroad junctions, and unloading areas.
- Screen flanks of attacking echelons.
- Use illumination rounds in conjunction with blinding smoke to destroy night vision on the objective and illuminate the target.
- Screen fronts of advancing maneuver echelons.
- Screen movement of guns and other weapon systems into firing positions and from position to position.
- Use smoke to screen the activities of engineer units when clearing minefield and to mark passages through engineer barriers.
- Use smoke to screen logistics routes and activities that are within range of our fire and observation.
- Use smoke to mark targets for aircraft, artillery preparation, and signaling purposes.
- Use blinding, camouflage, and decoy smoke to conceal the direction and time of attack to minimize losses.

Note: Reliable communication and continuous coordination among units making smoke, units using smoke, forward air warning assets, and air defense systems are essential.

Threat Offensive Smoke Use

Threat smoke doctrine states that they will use smoke whenever and wherever the tactical situation permits. The extent they use smoke in any offensive operation depends largely on the amount of time available to plan and coordinate for the use of smoke in support of the operation. Smoke usage is also dependent on other variables, such as weather, terrain, and the tactical situation. Nevertheless, we can deduce several doctrinal norms for our IPB in regard to Threat smoke use in the offense. Expect the Threat to—

- Use an intense initial artillery preparation with HE and smoke munitions fired for shock and suppression
- Use sustained HE fire to cause attrition to defenders; this also creates large quantities of dust that stay aerosolized after three to four volleys.
- Place blinding HE dust and smoke on or in front of defensive positions.
- Use smoke to deny acquisition, degrade armor or antiarmor guidance systems, and with toxic smokes create casualties.
- In the main attack area, make smoke three to five times wider than the zone of attack.
- On the Threat side of the FLOT, use smoke pots and generators and limited VEESS smoke to camouflage and protect the attacking force's advance from long-range helicopter and indirect fire.
- On the US side of the FLOT, use HE-created dust, projected WP/PWP smoke, and on-board smoke to degrade acquisition and armor or antiarmor guidance systems.
- Increase artillery tempo as attack force approaches the FLOT
- Shift HE and smoke fire to isolate the zone of attack when the attacker is 400 to 1,000 meters from our defense.
- Conduct the final assault unencumbered by their own obscurants
- After a Threat attacking force passes through the FLOT to our side of the FLOT, use consecutive lines of fire with HE and WP/PWP to provide additional blinding smoke.
- Use VEESS/grenades on the US side of the FLOT only on command of the company and battalion commander when required for additional protection.

Threat Smoke Example

The following example illustrates the Threat's use of smoke in the offense. The example does not include consideration of either terrain or local meteorological conditions; therefore, it is largely mission, enemy, terrain, troops, and time available (METT-T) independent. The example centers around the type, extent, and time frame in which the Threat would use obscurants. The example does not consider our countermeasures and does not represent US Army doctrine.

In meeting engagements, the Threat attempts to seize the initiative to either overwhelm or force the opponent into the defensive. These tactics generally occur when covering forces, guard forces, patrols, and units moving to contact encounter the enemy, either intentionally or unintentionally. They are normally conflicts of a few hours duration. A meeting engagement will probably occur more frequently than any other encounter and involve the least amount of deliberate use of smoke and obscurants.

A Threat reinforced motorized rifle battalion (MRB) has penetrated our defensive positions. A second-echelon unit has exploited the breakthrough by continuing the march into our rear area. At H - 9, both sides have located each other, with neither screening force large enough to initiate combat. Therefore, they remain in contact until either side can bring forward a larger force. The distance between the opposing forward elements is 1,300 meters. The CRP is part of the reinforced motorized rifle company (MRC), which is part of a reinforced MRB. The mission of the FSE is to destroy our reconnaissance forces and to destroy or fix our lead company, thereby fixing our force in position. Twenty minutes behind the FSE is the reinforced MRB (minus the advanced guard) that is to actually conduct the attack.

At H-hour supporting artillery deploy and fire a WP round from each of two 122-millimeter guns to mark the enemy's flanks. The FSE is moving forward and will establish the FLOT along the screen line of the CRP. The advanced guard is moving forward at a rate of 30 kilometers per hour.

The artillery and mortar units begin their fire at H + 1 minute, using HE rounds on the objective. The FSE has deployed along the FLOT with its attached tank platoon in the northern sector.

At H + 9 minutes, the FSE's combat vehicles initiate camouflage smoke with their VEESSs (Figure 1, next page). The artillery and mortar units increase their rate of fire. Two minutes later (H + 11 minutes) the two platoons in the northern sector shut off their VEESS and fire a half volley of their smoke grenades. These two platoons will distract attention from the advanced guard, which will conduct the actual attack along a more southerly axis.

At H + 12 minutes, the MRB (-) arrives at the FLOT and attacks through the area where the two motorized rifle platoons are still generating camouflaging smoke with their VEESS. Each of the two tank platoons from the attacking force now fires a half volley of grenades. The units that had previously fired their grenades to distract attention fire the rest of their grenades and begin to move forward.

At H + 13 minutes, the tanks from the main attacking formation fire the rest of their grenades as they

Table 3. Total Threat rounds used in example.

No. of Tubes	Type	Total Rounds Available	Total Rounds Used
NA	DM11 Smoke Pots	60	0
18	122-mm SP Howitzers	72 WP 1,296 HE 72 AT	56 666 0
6	120-mm Mortar	24 WP 432 HE	24 360

continue to attack forward. The feint has stalled and is now unobscured. HE rounds are still falling on the objective (Figure 2, below).

The mortar and artillery units start firing an HE/WP mix at H + 15 minutes.

At H + 16 minutes, Threat fire shifts to the rear of the defensive positions to isolate our force.

For a list of total obscurant and artillery assets used by the Threat in this example, see Table 3.

Threat Defensive Smoke Use

Threat defensive smoke use can be grouped into two broad categories. These are smoke for protection from fire and smoke to disrupt and defeat advancing forces.

Smoke for Protection

Examples of Threat smoke usage for protection include the following

- To camouflage the maneuvers of their subunits of tanks, infantry, and artillery.
- To conceal engineer activities from our observation.
- To screen replacements of first-echelon units and subunits under conditions of good visibility.
- To camouflage the approach of their subunits for counterattack.
- To ensure flank and maneuver security.
- To mislead our forces on the disposition of second echelons and reserves and planned counterattack directions.
- To conceal the withdrawal of the battle outpost.
- To counter our reconnaissance, intelligence, target acquisition, and weapon guidance and control systems.
- To protect targets from laser designators.
- To blind our observation posts and forward observers.
- To conceal engineer breaching operations.
- To conceal aerial reference points.
- To defeat the light and heat effects of nuclear weapons.

Smoke to Disrupt and Defeat Advancing Forces

The Threat also will use smoke while in the defense to slow, disrupt, and defeat our advancing forces. Several Threat writings expressed concern over identifying targets set against forest or brush backgrounds. For this reason, the Threat developed techniques involving the use of smoke and illumination rounds to serve as an artificial background. This makes target identification easier. These techniques involve firing mortar and/or artillery smoke rounds 50 to 100 meters beyond our advancing forces. Then they place illumination rounds just

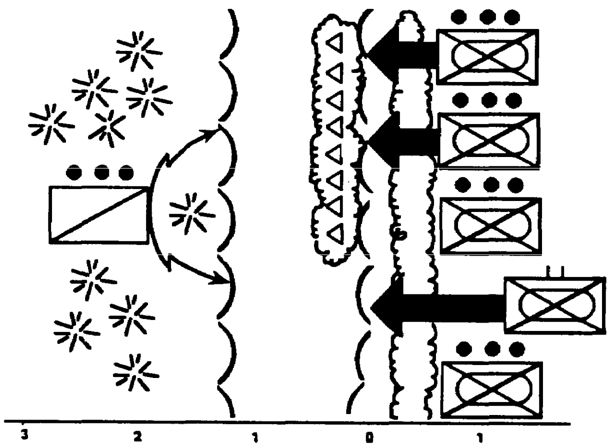

Figure 1. FSE vehicles start the VEESS smoke while artillery prepares the objective with HE, thus concealing the movement of the MRB as it prepares to attack through the FSE.

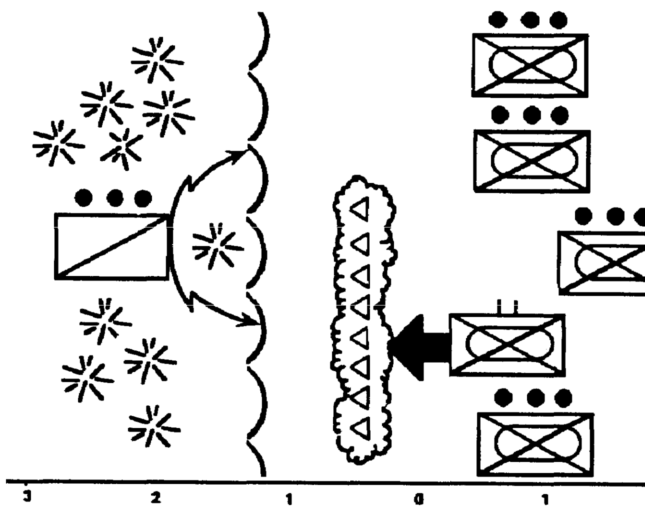

Figure 2. The FSE vehicles stop making smoke, and the MRB emerges from the smoke in position to assault the objective.

beyond the smoke to illuminate the background from the rear. This creates favorable conditions for observation and acquisition.

Also, Threat doctrine states that smoke deprives our units, when shrouded in smoke, of the capability to conduct observation of the field of battle. Smoke will make fire control and navigation more difficult. As a result, our attacking forces can stray off course from the specified directions and get mixed up with each other. There is potential for us to reduce or not aim our fire, creating favorable conditions for Threat second echelons and reserves to deploy, seize the initiative, and counterattack.

Threat Smoke Example

The best illustration of Threat smoke use in the defense is a Threat hasty defense versus a friendly deliberate attack. In the following scenario, Threat forces have attacked and are well within our territory. Threat forces have already made an unsuccessful attempt to attack from a position in contact.

The Threat force commander is preparing to conduct an attack from a position in contact. Before he can initiate this attack we attack. Two minutes after our forces begin their preparatory fire, Threat artillery uses counterbattery fire with HE onto our scout platoon.

When their forces have identified our axis of advavce, they begin to establish an obscuring line, using WP and illumination rounds approximately 150 to 200 meters in front of our FLOT. When our attackers emerge from the smoke, Threat forces engage them with ATGM weapon systems.

The Threat will establish a second obscuring line approximately 900 meters in front of our FLOT, using HE and WP fire. Again, ATGM fire will engage our attacking forces when we emerge from the smoke. As our forces reach the point 1,000 meters from the the Threat's FLOT, they will engage us with HE munitions from a 122-millimeter multiple rocket launcher.

Commander's Considerations

Even the most sophisticated weapon systems are limited by terrain and weather. Prior planning by the S2/G2, S3/G3, and the chemical officer can increase the limitations of enemy systems with man-made obscurants. The commander will have to decide how smoke and obscurants will affect his ability to conduct the direct fire fight. Given the various types of EO devices and the number of visual and bispectral obscurants that will be common on any future battlefield, the answer to this question is not easy. The Soviets may not have thermal imagery sights on their weapon systems. However, other potential adversaries are attempting to acquire or already have the systems. During any future conflict, you must know your enemy. "What?" "When?" "Where?" "How?" and "With how many?" will always be the questions to answer. Other PIRs to determine the effects of obscurants are the—

- EO system capabilities of the ememy force.
- Extent of their employment: whether on reconnaissance systems, direct fire systems, or all systems.
- Smoke delivery capabilities of the enemy force.
- Extent of enemy smoke employment.
- Directed-energy weapon capabilities of the enemy force.

We use smoke and obscurants to attack Threat EO systems and to protect our force. Smoke and obscurants can change the number of effective weapon systems available to either force. Once the commander decides to use smoke and obscurants, the outcome of the battle and the proficiency of his intelligence, operations, and chemical officers will determine the effectiveness of his weapons.

The four examples in Figure 3, on the next page, illustrate how smoke affects the number of enemy weapon systems that can engage the combat battalion. Example 1 depicts the force ratio when smoke is not used. In this example, the standard force ratio is Threat forces 6.4:1 over friendly forces. In examples 2 through 4, the same size force uses equal amounts of smoke and puts it in the same location. However, the force ratio changes in each example based on the relative abilities of opposing weapon systems to see through the smoke and engage targets.

Example 2 shows that the Threat use of smoke degrades the enemy's own force combat power when we have ATGMs with thermal sights (for example, TOW II). TOW II can see and shoot through most smokes. This increases our force ratio (2.5:1) over that depicted in example 1 (1:6.4) by removing all Threat long-range direct fire weapons while not significantly degrading friendly long-range tank main gun (M1) and missile shots (IFV and ITV).

In example 3, we use smoke against a high-technology threat. Our use of smoke degrades the Threat's combat power when we have the TOW II. The force ratios are the same as in example 2. In example 4, we use smoke against a low-technology threat. This eliminates the Threat's ability to fight the direct fire fight since none of the enemy's long-range fire systems can see through smoke. In this case, our force ratio significantly increases (8:1). Friendly forces are able to engage the Threat's entire force.

We could describe an infinite number of combinations of smoke and weapon usage; therefore, com-

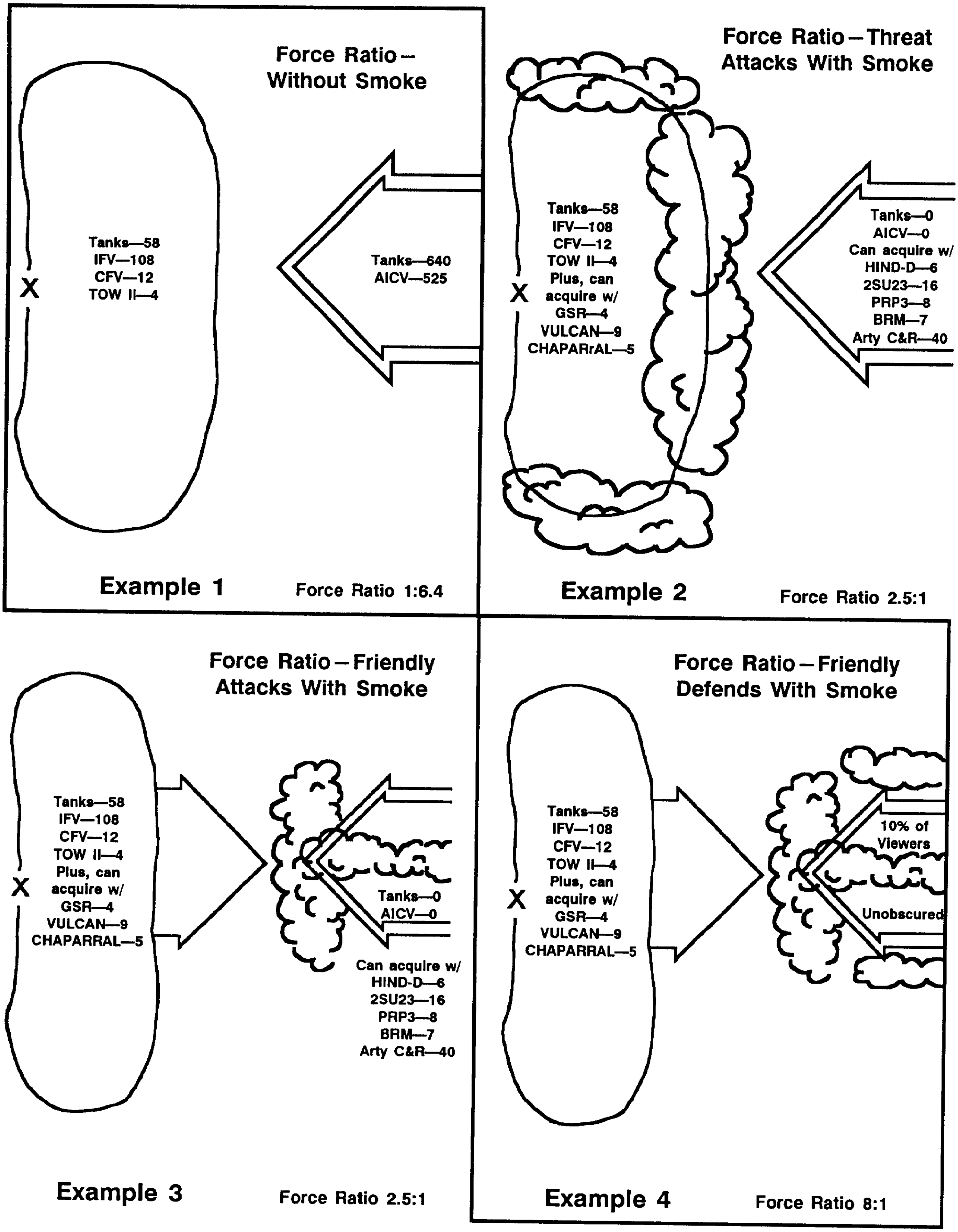

Figure 3. How smoke can change force ratios in the attack and defense.

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manders must consider the following principles when using smoke:

- Smoke usage can change the number of effective weapon systems available to either force.
- Smoke effectiveness is directly related to the relative ability of Threat direct fire systems to see and shoot through smoke.
- Employing smoke improperly can degrade friendly combat potential. When in doubt, employ smoke only when you can see and fire through it. Know your ability and that of your enemy to see and fire through smoke. Plan the battle accordingly and never leave smoke employment to chance.

US Countermeasures to Threat Use of Smoke

Threat smoke and obscurant use has the potential for significantly degrading both our defensive and offensive operations. In general, there are two options available to counter enemy smoke use: Move to alternate positions on the battlefield to continue unimpaired operations, or use EO devices that allow operations to continue under smoke.

Our forces must first understand Threat doctrine regarding use of smoke and obscurants to anticipate when and where the Threat will employ them on the battlefield. Next, our commanders must train their units to operate in periods of limited visibility where target acquisition, navigation, and command and control are confusing and difficult. Finally, we must train and use tactics, techniques, and procedures that overcome or minimize the effectiveness of Threat smoke and obscurant usage.

Obstacles

Obstacles placed along the enemy's most likely avenue of advance can slow them, disrupting their timetables. Preplanned fire on these positions can be an effective means of engaging the enemy even in dense concentrations of smoke.

Acquisition devices that are less sensitive to smoke and obscurants can acquire the enemy at choke points and/or barriers and then direct engagement by direct and indirect fire. Obstacles can delay one element of the attacking force, drawing an adjacent element into an engagement area, unable to receive supporting fire. Separation of forces may also occur due to the enemy's own use of smoke.

Dispersion

Dispersing our forces laterally and in depth places a greater burden on attacking fire. Combining dispersion with rigorous counterreconnaissance measures forces the Threat to expend more resources and take greater risks in conducting attacks. The more dispersed you are, the more difficult and costly it is for the Threat to bring blinding smoke fire on your positions. Additionally, dispersing in depth aids in obtaining flanking fire where the Threat smoke is much less concentrated.

Deception

Tactical deception can cause the Threat to ineffectively use smoke assets. For example, an effective ruse might cause the enemy to expend greater resources in attempting to blind friendly gunners and camouflage tank movement. This would reduce overall smoke effectiveness. Using deception means may also cause the enemy to attack in the wrong direction and become silhouetted against their own smoke, allowing us to effectively engage their force without smoke degrading our line of sight.

Friendly Countersmoke

Friendly forces can use smoke and obscurants to counter enemy use of smoke as control measures or phase lines. Friendly visual obscurants can flood the area between friendly defensive positions and enemy smoke lines to disorient the enemy and deceive them as to the actual battle positions. At the same time, friendly units can engage the enemy using thermal imagers and direct fire weapon systems.

Engagement of Enemy Forces in March Formation

The Threat does not plan as much smoke to protect the force while they are still behind the FLOT. If we engage enemy march formations, less enemy smoke use should enhance our fire.

Limited Visibility Positions

Threat doctrine calls for the Threat to lift all smoke when they come within 1,000 meters of their objective. Using alternate positions forward of your main defense will cause attrition in their attacking force and disrupt their timetables, creating surprise and confusion when they emerge from their final smoke screen. However, the use of any alternate positions increases the need for countersurveillance and counterreconnaissance measures.

Occupation of reverse slope positions coupled with alternate or dummy positions on the forward slope can cause the enemy to waste artillery assets and give friendly defenders more time to react when enemy attackers emerge from their own smoke.

Stay-Behind Forces

Stay-behind forces using nonlinear tactics can engage an enemy from their flanks and rear where they are often unobscured.

Positioning of Observers and Observation Devices

Position forward observers, warning systems, and ground/vehicle laser locator designators (G/VLLDs) where they are less likely to encounter obscuration during the battle. The highest point of a battle position normally offers the best lines of sight for laser designators. However, because of the vulnerability of these G/VLLDs to smoke and obscurants, commanders should attempt to avoid blinding by placing these devices on the flanks of a battle position.

Targeting of Enemy Smoke Assets

In addition to passive countermeasures, we can also take active steps to reduce the obscurant threat. Using IPB with a thorough understanding of how the enemy employs smoke assets, we can determine the location of those smoke assets. Once located, enemy artillery and smoke generator units are extremely vulnerable to friendly fire.

Ground Surveillance Radar

Employ ground surveillance radar (GSR) with maneuver elements to direct, identify, and locate targets in smoke. Ensure our own obscurant operations do not mask GSRs with millimeter wave obscurants and that GSRs can continue to provide targeting data to commanders when smoke obscures other surveillance means.

Use of Threat Smoke to Conceal Our Maneuver

When the Threat uses smoke between their forces and ours, we can exploit the fact that they are as likely to be unable to see through it as we. We can use their smoke to aid in obtaining surprise for our own attack or counterattack.

Use of Friendly Aviation

Use friendly aviation assets to identify gaps in smoke coverage. Target hand-off procedures must facilitate air and ground target engagement.

Preplanned Disengagements

Execute preplanned disengagement based on remote signal devices rather than visual cues. Use a thorough IPB to establish the key event for disengagement on your decision support templates.

Air Defense Positions

Position air defense assets where they obtain the most benefit from enemy smoke. Emplace systems requiring visual target acquisition (for example, Vulcan and Stinger) on high ground clear of the smoke. Use them to look over the smoke and engage low-flying helicopters and aircraft that silhouette against the smoke. Emplace air defense systems using thermal or millimeter wave acquisition in the smoke to mask missile launch points.

Chapter 3

Offensive Operations

The offense is characterized by violence, concentration of friendly forces, disruption of hostile forces, and rapid transitions between different types of operations. Smoke and obscurant use multiplies the commander's ability to project combat power at the critical time and place to defeat the enemy. Smoke and obscurant use will support any type of offensive operation at any level because smoke generally favors the attacker.

Historical Perspective

The most recent and perhaps most significant example of smoke in a combat multiplier role occurred during the 1973 Arab-Israeli War. On 6 October 1973, at 1400 hours, Egyptian forces attacked prepared Israeli positions defending the west bank of the Suez Canal. The Egyptians initiated the attack by deploying 200 attack aircraft into the Sinai to destroy Israeli communications centers, airstrips, and artillery positions (Figure 4).

Within moments, Egyptian artillery opened up with a massive barrage of high-explosive munitions and blinding smoke. The Egyptians intended to degrade the ability of the Israelis to engage targets and adjust artillery fire with that blinding smoke. It accomplished its purpose with devastating results; it induced a feeling of total isolation among defending Israeli units. The fear caused by the addition of yellow smoke to the artillery preparation amplified the psychological effects of isolation. The defenders believed they were being gassed.

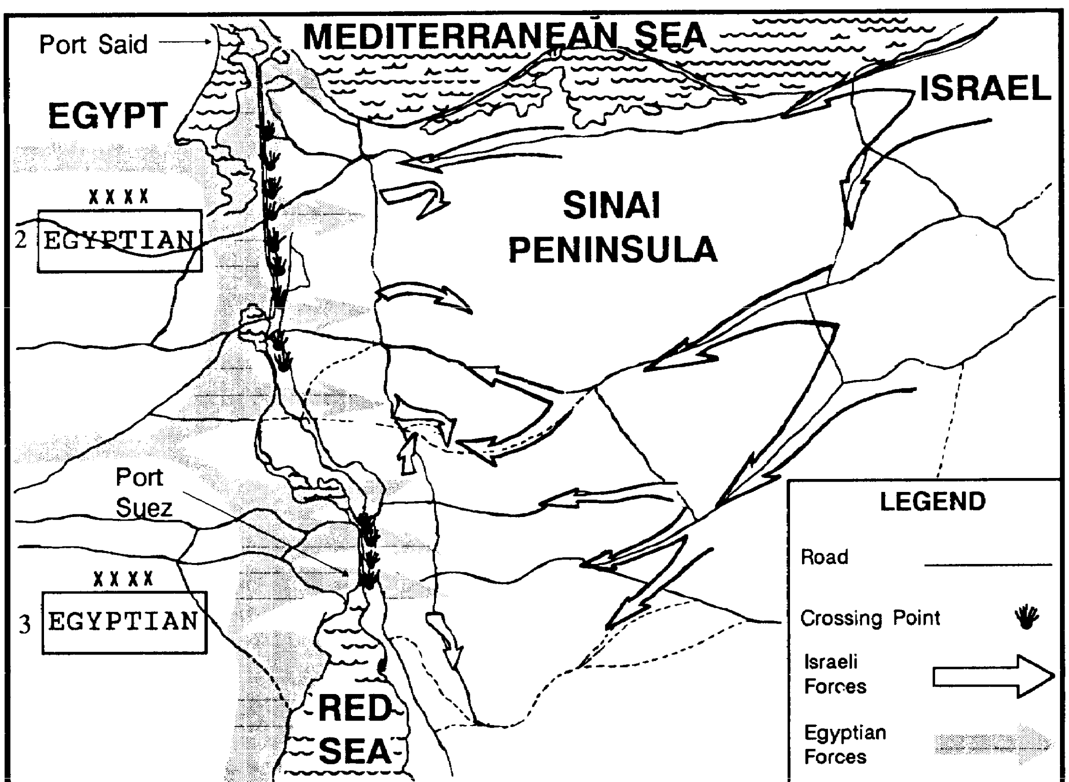

Figure 4. Egyptian assault crossing under smoke at the Bar-Lev Line in 1973. The Egyptian force, indicated by the darker arrows, crossed at mid-day under heavy smoke, and surprised the Israeli forces.

Minutes later Egyptian armored and artillery assets began to deploy forward to firing positions on their side of the canal. These units engaged the Bar-Lev strongpoints with direct fire while infantry units conducted a forced crossing in dinghies under the cover of canister-generated smoke. Air-mobile operations placed commando units 10 miles into the rear to disrupt reinforcing echelons. Egyptian engineer units emplaced bridges over the canal. Smoke from artillery, canister, and smoke generator assets supported the engineer effort.

These actions demonstrated the tremendous impact of smoke when synchronized with a combined arms assault. Within the first 24 hours of the attack, the Egyptians accomplished the almost impossible: They had moved five divisions, 100,000 men, 1,020 tanks, and 13,500 vehicles across the canal and established a bridgehead six miles into the Sinai. The Israeli forces lost 150 tanks, almost one-tenth of their total in the Sinai. The blinding smoke placed on the Bar-Lev strongpoints effectively reduced the Israeli ability to acquire targets and spot for attack aircraft.

The Egyptian Army was eventually driven back and sustained considerable losses. Nevertheless, their forced crossing of what the Israelis believed to be the largest tank ditch in the world was a complete success. The effect that smoke played in that operation was significant. While the crossing may have been effective without smoke, the Egyptian forces could have sustained far greater casualties, and the crossing could have taken far longer to complete without the cover of smoke.

Tactics

The National Training Center (NTC) is an area where smoke training is possible on a large force-on-force scale. MG E. S. Leland, former commander of the NTC, stated, "Smoke is a far more significant battlefield factor than I used to believe. It simply must be a major planning consideration in terms of both friendly employment and reaction to enemy use."

Key insights from the NTC for the offense include the following:

- Smoke favors the attacker.
- Smoke tightens attack formations.
- We must capitalize on thermal imager capability.
- We must plan command and control without visual cues.
- Training and rehearsal are the keys to success.

Smoke and obscurants integrated throughout the offensive framework provide major contributions to combat power in deep, close, and rear operations. In the offense, use smoke to—

- Support maneuver by—
  – Concealing maneuvering forces from enemy observation.
  – Providing tactical surprise and allowing the commander to set the terms of combat.
  – Allowing the commander to mass forces unobserved.
  Defeating enemy surveillance efforts.
  – Supporting the deception plan.
- Provide additional firepower by—
  – Changing friendly to enemy force ratios by using thermal imagers and millimeter wave acquisition devices such as radars to see through visual smokes and using smoke to isolate defending and second-echelon forces.
  – Defeating enemy counterreconnaissance efforts.
  – Enhancing friendly target acquisition efforts by silhouetting enemy vehicles with smoke and using smoke and obscurants we can see through but the enemy cannot.
  Disrupting enemy maneuver and reinforcement.
  – Disrupting the enemy's ability to communicate.
- Protect the force by—
  – Reducing friendly force vulnerability by concealing support forces from enemy observation and defeating enemy reconnaissance efforts.
  – Concealing obstacle breaching.
  – Defeating enemy weapons by defeating enemy target acquisition efforts, defeating enemy guidance systems, and negating standoff capability of enemy long-range direct fire weapons.
  – Degrading or defeating enemy directed-energy weapons.

Use

Smoke and obscurant use in the offense requires careful planning and execution to prevent interference with movement, assault operations, or target acquisition; to retain the element of surprise; and to avoid silhouetting or drawing undue attention to friendly forces.

Smoke use is not without risks. Our use of smoke must increase friendly force survivability without seriously degrading operational capabilities. It must decrease Threat force command, control, communications, and intelligence gathering capabilities (C3I).

In addition to the general employment techniques detailed in Chapter 1, techniques to minimize interference in the offense include the following:

- **Use covered and concealed maneuver techniques.** Assume the enemy can see through the smoke. Do not take unnecessary risks with the force.
- **Time smoke delivery with decision points.** Conduct a thorough IPB and time your use of smoke to key decision points in your tactical plan: for example, "When we reach Hill 285, we will call for A Battery to fire smoke and HE onto target XY1007 and sustain that fire to obscure enemy observa-

tion of our flanking of Objective White."

- **Use unobscured weapons to overwatch.** The overmatching elements should have target acquisition devices such as thermal imagers that can see through our own smoke and engage the enemy. This prevents surprise and enhances the ability to suppress enemy fire during the assault.
- **Do not let your own smoke silhouette your forces.** Never overrun your smoke cloud prior to the final assault. "Walk smoke in" towards enemy positions wherever possible. This ensures your forces remain concealed and confuses the enemy as to your exact location and intent.
- **Plan to engage through or around the smoke.** Plan to use weapon systems that can acquire and fire through the smoke. Plan limited visibility positions for those systems that smoke degrades (for example, position target acquisition assets on flanks or above smoke).
- **Plan for enemy countermeasures.** Enemy forces will counter your smoke use. Plan to intensify your counterreconnaissance and air defense efforts. The enemy may use countersmoke to confuse your command and control, so avoid reliance on visual signals. The enemy will increase use of indirect fire weapons when direct fire target acquisition is ineffective. Therefore, plan artillery counterbattery and countersmoke fire after crossing the line of departure/line of crossing (LD/LC).
- **Plan for additional maneuver time under smoke.** Smoke slows maneuver. Base the planning factor on METT-T and the proficiency of your unit to operate under smoke as shown in previous combat (or training) operations.
- Verify enemy locations (responsibility of reconnaissance). The enemy can use both our smoke and theirs to conceal movement to alternate positions or to break contact. Aggressive reconnaissance before and during the engagement will allow you to shoot and remain in contact.

Goal

The main focus of smoke in the offense is to defeat enemy RSTA efforts, conceal maneuver and support forces, and contribute to tactical deception operations. Our intent is to deny the enemy information about the disposition and composition of our forces, which provides surprise and security. It also allows the commander the flexibility to mass the forces required to conduct attacks. The next section presents the tactics for using smoke in offensive operations. Appendix A contains tactical decision aids for determining which smoke delivery means to use against the specific smoke targets covered by these tactics.

Phases

The phases of the offense are preparation, attack, exploitation, and pursuit.

Preparation

The preparation phase of offensive operations involves the concentration of attacking forces and associated support elements into contact with the enemy.

The overriding imperative in a movement to contact is initiative.

Use smoke to –

- Conceal movement of maneuver and support forces, allowing the commander to mass forces unobserved.
- Provide tactical surprise, allowing the commander to seize the initiative and set the terms of combat.
- Defeat enemy reconnaissance and counterreconnaissance efforts.
- Conceal obstacle breaching or crossing.

Smoke employment tactics in the preparation phase are the following:

- Screening smoke. Use screening smoke to conceal maneuver and obstacle breaching or crossing. Use smoke in the main body area and along the flanks to conceal movement. You must carefully control the smoke to prevent silhouetting your units. Begin making smoke prior to crossing the line of departure to confuse the enemy as to the actual location and size of the force.
- Protecting smoke. Use protecting smoke as required to defeat enemy ATGMs and air defense systems.
- Obscuring smoke. Use obscuring smoke to defeat enemy reconnaissance and counterreconnaissance efforts. Use projected smoke means to deliver smoke mixed with high-explosive rounds before the enemy can pinpoint your units. Plan obscuring fire based on decision points for the enemy, isolating and confusing their reconnaissance forces.
- Marking smoke. Use smoke to mark enemy targets for rapid destruction or to reduce the potential for firing on friendly forces.
- Smoke for deception. Use this smoke to draw attention to areas of little or no importance. Create large-area smoke away from the main body. Consider using smoke mixed with high-explosive rounds to conduct preparatory fire on dummy objectives.

Figure 5, on the next page, illustrates smoke employment in the preparation phase.

Attack

A hasty attack will normally immediately follow a movement to contact. If the contact reveals an overwhelmingly superior enemy force, or our hasty attack is unable to either outflank or overcome the enemy defense, we will conduct a deliberate attack. In the attack phase, use smoke to—

- Provide tactical surprise, allowing the commander to seize the initiative early.
- Conceal movement of maneuver and support forces, allowing the commander to mass forces unobserved. Smoke must provide the commander with the ability to concentrate the maximum possible shock and violence against the enemy.
- Ruin the enemy commander's synchronization.

- Conceal obstacle breaching or crossing.
- Defeat enemy target acquisition, weapon guidance, and directed-energy weapon systems.

The overriding imperative in hasty attacks is agility. Therefore, smoke use in a hasty attack must assist the commander to fix and contain the enemy, deploy into combat formations, and maneuver additional forces to the flank and rear where the enemy is destroyed by fire or assault.

Smoke employment tactics in a hasty attack include obscuring smoke, screening smoke, marking smoke, protecting smoke, and deceptive smoke:

- Obscuring smoke. Use obscuring smoke to isolate the objective, defeat enemy target acquisition and guidance systems, and defeat reconnaissance and counterreconnaissance efforts. Use projected smoke means to deliver smoke mixed with high-explosive rounds in front of the objective; between enemy formations; and on identified forward observer, ATGM, and tank unit positions before the enemy can pinpoint your units as targets. Using projected smoke as countersmoke and to isolate the objective can significantly interfere with the enemy commander's synchronization.
- Screening smoke. Use screening smoke to conceal maneuver as you bypass small pockets of resistance and breach obstacles. Use it also along the flanks to protect the force and in the rear to conceal disposition and composition of reserves. Use self-defense and generated-smoke means to deliver smoke across danger areas and to the flanks of the force to limit enemy observation and engagement.
- Marking smoke. The tactics are the same as in the preparation phase.
- Protecting smoke. The tactics are the same as in the preparation phase.
- Deceptive smoke. The tactics are the same as in the preparation phase.

The overriding imperative for the **deliberate attack** is synchronization. Therefore, smoke use in the deliberate attack must assist the commander to fix and maneuver against the enemy and prevent the enemy from breaking contact. It must also force penetration of the enemy's defense and prevent reinforcement or counterattack by enemy reserves or second-echelon forces. Smoke employment tactics in a deliberate attack have the same names as for the preparation phase, but read on.

- Obscuring smoke. Use obscuring smoke to isolate the objective and complement countermobility efforts. Use it also to defeat enemy target acquisition and guidance systems and defeat reconnaissance and counterreconnaissance efforts. Use projected smoke means to deliver smoke mixed with high-explosive rounds in front of the objective, between enemy formations, on identified forward observers, and on ATGM and tank unit positions before the enemy can pinpoint your units as targets. Use smoke mixed with scatterable mines for countermobility behind enemy positions. Use it also between the enemy first-echelon, reserve, and second-echelon forces. The critical activity in planning obscuring fire in the deliberate attack is synchronization of all direct fire, fire support, smoke support, and engineer assets to create maximum combat power.

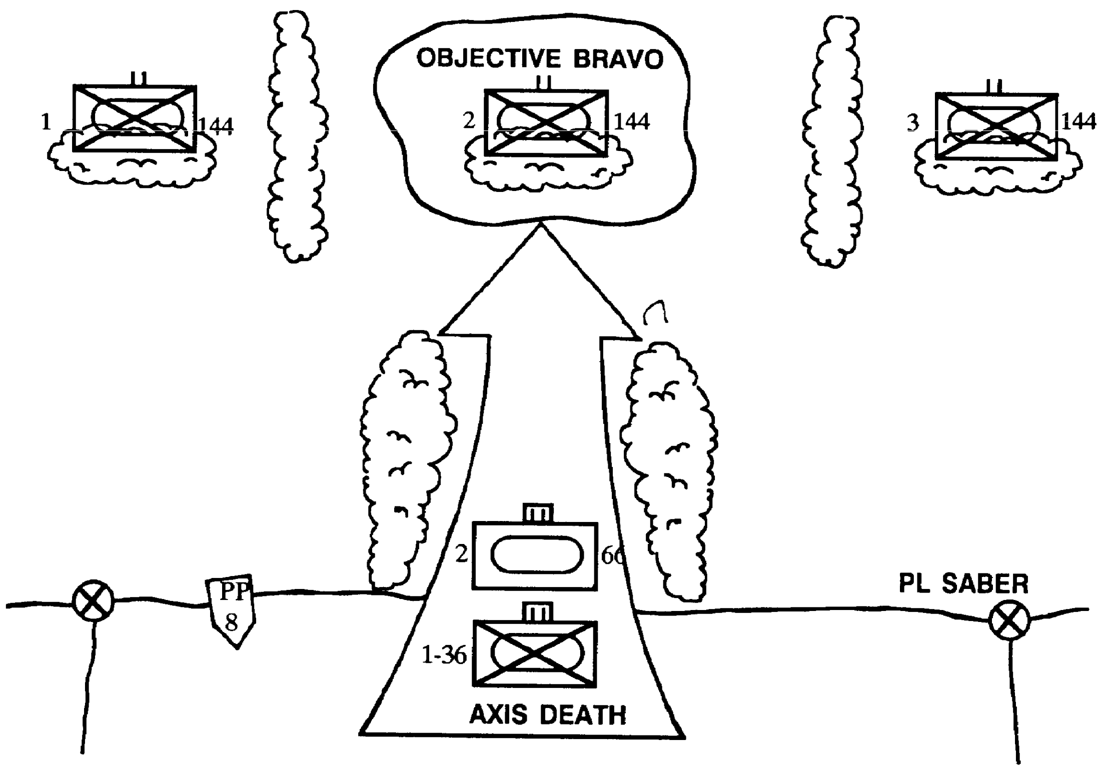

Figure 5. This example of employment in the preparation phase uses mechanized smoke units on the flanks of Axis Death to protect the force. Projected smoke and HE fired at TAIs blind the enemy recon assets and isolate enemy formations from each other. By suppressing enemy RSTA efforts, the brigade can close on the enemy without significant losses.

- Screening smoke. Use screening smoke to conceal maneuver as you cross the line of contact, bypass small pockets of resistance, or bypass or breach obstacles; along the flanks to protect the force; and in the rear to conceal disposition and composition of reserves. Use large-area generated smoke to conceal passage of lines and confuse the enemy concerning the disposition and composition of your force. Reconnaissance of enemy obstacles is critical to ensure timely employment of large-area smoke to conceal breaching or crossing of obstacles. Use self-defense and generated-smoke means to deliver smoke across danger areas and to the flanks of the force to limit enemy observation and engagement.
- Marking smoke. Use marking smoke to mark enemy targets for rapid destruction or to reduce the potential for firing on friendly forces. Use projected smoke means such as helicopter rockets to mark close and deep targets for engagement by close air support aircraft.
- Protecting smoke. If the enemy has known or suspected directed-energy weapon capability, concealing your force in a blanket of oil smoke will attenuate some of the energy. In the far term, using large-area projected smoke containing millimeter wave obscurants directly on the enemy positions will reduce our vulnerability to directed-energy weapons,
- Smoke for deception. Use supporting smoke to draw attention away from the main effort to areas of little or no importance. Use generated-smoke means (in a deliberate attack, the best means may be smoke pots and generators) to create smoke away from the main body. The deception story must be integrated into the overall tactical plan for smoke use to be effective.

Exploitation

Commanders should plan to follow every attack by bold exploitation to keep the enemy under pressure, compound their disorganization, and erode their will to resist. The overriding imperative in exploitation is depth. In the exploitation phase, use smoke to—

- Ruin the enemy commander's synchronization.
- Isolate enemy forces, allowing the commander to keep the enemy in contact and under pressure.
- Conceal movement of maneuver and support forces, allowing the commander to protect logistical units and convoys required to sustain the momentum of the exploiting force.
- Defeat enemy target acquisition, weapon guidance, and directed-energy weapon systems. This is particularly important as the exploitation force bypasses or contains small groups of enemy forces.

Smoke employment tactics in the exploitation phase use the same five types of smoke as follows:

- Obscuring smoke. Use obscuring smoke to complement countermobility efforts, defeat enemy target acquisition and guidance systems, and isolate enemy forces for piecemeal destruction. Use projected means to deliver smoke mixed with high-explosive rounds onto targets between enemy formations, onto enemy units as they attempt to regroup, and in front of enemy strongpoints as you bypass them. Use smoke mixed with scatterable mines behind moving enemy formations to impede their ability to break contact and to compound their disorganization.
- Screening smoke. Use this smoke to conceal maneuver and support forces and defeat enemy target acquisition and guidance systems. As protection of supplies and support units is essential to maintain the rapid tempo of the exploitation, priority of effort for smoke assets must go to sustainment activities. Use generated-smoke means to deliver smoke onto key logistics activities and to protect convoys. Use self-defense and generated-smoke means to conceal maneuver units as they bypass or harass enemy forces.
- Marking smoke. Use marking smoke to mark targets for destruction, identify bypass routes, and signal for battlefield activities. Use projected smoke means to deliver smoke onto identified enemy strongpoints or larger formations and to signal forces to consolidate on a particular objective or rally point. As exploitation force commanders rely heavily on air cavalry units for reconnaissance, helicopter-delivered smoke rockets will provide the best delivery system. Use generated-smoke means to mark bypass routes (for example, scouts could drop smoke pots at 100- to 200-meter intervals along a bypass route).
- Protecting smoke. The risk of nuclear weapon use increases when conventional means are ineffective in stopping our advance. If the enemy has known or suspected nuclear or directed-energy weapon capability, concealing your logistics activities in oil smokes may attenuate some of the energy.
- Supporting smoke for tactical deception. Use supporting smoke to keep the enemy off-balance and to draw attention away from critical sustainment activities. Use generated-smoke means to deliver smoke to multiple locations to the rear of the exploitation force to force the enemy to expend resources to target logistical activities.

Pursuit

As the enemy becomes demoralized and their formations begin to disintegrate, exploitation may develop into pursuit. Commanders attempt to annihilate the enemy force using a direct pressure force that keeps the enemy units in flight and an encircling force to envelop, cut off, and destroy or capture the fleeing enemy force. In the pursuit, use smoke to—

- Ruin the enemy commander's synchronization, denying the enemy time to reorganize a cohesive defense. If the enemy is able to establish a perimeter, smoke must help to defeat enemy target acquisi-

tion, weapon guidance, and directed-energy weapon systems.

- Isolate enemy forces, allowing the commander to keep the enemy in contact and under pressure.
- Conceal movement of maneuver forces, allowing the commander to envelop the enemy force.

Smoke employment tactics in the pursuit include the following applications of the five basic smoke types:

- Obscuring smoke. The tactics are the same as in the exploitation phase. Additionally, use generated smoke from the direct pressure force towards the enemy to obscure their observation while giving the encircling force freedom of maneuver. When in place, the encircling force could use generated smoke towards the enemy to obscure our forces, silhouette the enemy, and generally increase the enemy commander's synchronization problems.
- Screening smoke. Use screening smoke to conceal maneuver forces and defeat enemy target acquisition and guidance systems. Since the encircling force generally advances on parallel routes, screening smoke along the flanks of the encircling force can conceal their maneuver. However, since smoke draws attention, you may risk losing the element of surprise. Use self-defense and generated-smoke means to conceal maneuver units as they bypass or attack enemy forces.
- Marking smoke. The tactics are the same as in the exploitation phase.
- Protecting smoke. The tactics are the same as in the exploitation phase.
- Smoke for deception. Use this smoke to keep the enemy off-balance and to support hasty attacks if the enemy is able to establish a perimeter. Use smoke generators to deliver smoke to multiple locations creating false passage points and to draw attention away from the main effort.

Figure 6, below, illustrates smoke employment in the exploitation and pursuit phases.

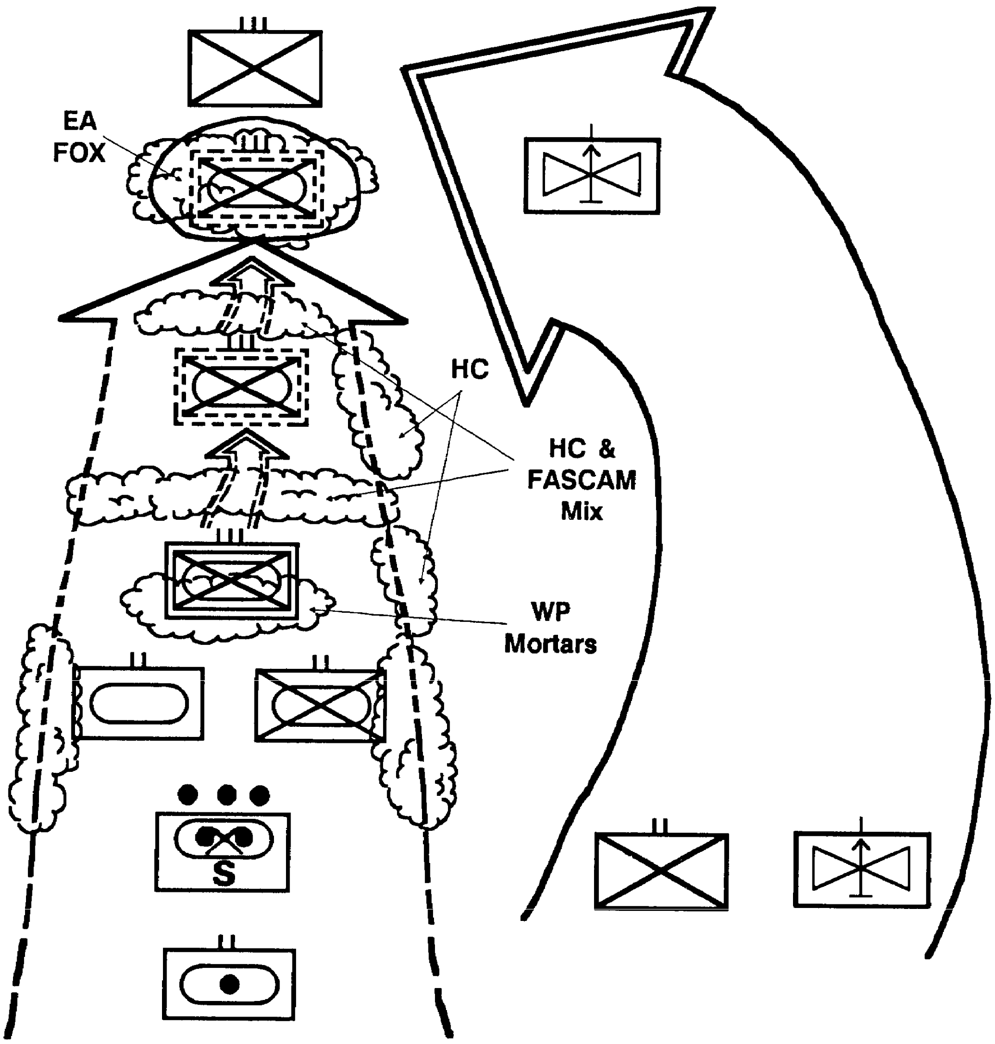

Figure 6. In this pursuit phase example, we are using FASCAM at choke points behind the enemy formation. As the enemy nears the choke points, artillery-delivered HC smoke further delays and complicates enemy command and control. Our lead task force in the direct-pressure force mixes HE and WP on the enemy formation, delaying it. The artillery fires HC smoke on the flanks to mark the flanks and to protect the movement of the encircling force. As the enemy emerges from the smoke in EA Fox, they are silhoutted against it and engaged by our direct fire weapons.

Attack Scenario

The following scenario illustrates possible smoke employment options in the offense, from the preparation through the pursuit phases. It depicts a mechanized infantry heavy brigade conducting the movement to contact. The brigade is the 2d Brigade, 54th Infantry Division (M).

Smoke delivery means include the direct support artillery battalion, battalion mortars, smoke generator platoon, VEESS, smoke pots, smoke grenades, and aviation assets on-call. Field expedient smoke delivery means include smoke pots strapped to armored vehicles with electrical ignition wires running inside the vehicle.

2d Brigade will conduct a movement to contact commencing at H-hour today. The commander's intent is

to reestablish contact with the enemy, seize the brigade objective, and exploit any success onto the division objective. The brigade objective is Objective Fox. The brigade's follow-on objective is Objective Jack. The division objective is Objective Midas some 40 kilometers beyond the line of departure.

Intelligence indicates that the enemy is the 1st Guard Motorized Rifle Division, 2d Combined Arms Army, which relieved another motorized rifle division and is conducting a meeting engagement from the march. The enemy is marching by regiments, with three regiments in front and a combined arms reserve instead of a second echelon. Terrain is fairly open to the west of Hill 268 but is restricted to the east of Hill 352. The enemy has excellent observation and fields of fire from both hills. Figure 3-6 illustrates the disposition of forces as of H-1 hour.

At H – 24 hours, the commander issues the restated mission and his planning guidance. The brigade chemical officer, S2, and FSO go to the intelligence cell and begin target development.

The brigade chemical officer has completed his estimate at H – 18 hours and provides a draft target list to the FSO. While the brigade chemical officer briefs the commander, the brigade chemical NCO continues smoke target analysis in coordination with the smoke platoon leader.

At H – 15 hours, the brigade chemical officer, FSO, and smoke platoon leader finalize the smoke support plan. This includes a draft smoke support annex to the brigade OPORD.

Preparation Phase (Movement to Contact)

Prior to H-hour the security force and flank security elements prepare expedient smoke devices using smoke pots strapped onto their vehicles. The fire support plan includes quick smoke to isolate the enemy combat reconnaissance patrols (CRPs), so WP and HC smoke ammunition is pre-positioned forward of the artillery battalion in the security force area.

The fire support plan also calls for aviation assets to use smoke rockets to mark the gaps between the enemy CRPs and FSEs. The S3 (air) has coordinated for the attack helicopter squadron to carry extra WP rockets in their first two sorties. The smoke platoon initially travels with the main body and has on-board capability to make smoke for 70 to 140 minutes.

At H-hour, our forces cross the line of departure.

Thirty minutes !ater, aviation reconnaissance sights the lead elements of the enemy CRP. When the CRP is within 3,000 meters of the security force, the artillery battalion fires HE and smoke (HC) in front of each CRP.

At H + 35 minutes, the security force sights the CRP through the smoke using thermal imagers. The security force then attempts to fix the CRP by engaging it with direct fire weapons through the smoke.

At H + 36 minutes, the security force will also locate and mark bypass routes. The security force ignites smoke pots and drops them off at 200-meter intervals to mark and conceal the bypass.

The smoke platoon moves toward the LD at H + 36 minutes. NOTE: The smoke platoon should always remain behind the security force.

At H + 38 minutes, the aviation reconnaissance and security force sight the enemy FSE. The FSE is moving forward to establish the FLOT along the screen line of the CRP.

At H + 39 minutes, the maneuver battalion mortars begin to fire HE and WP on top of and in between the CRPs. The artillery battalion shifts fire to the area between the FSEs and CRPs, obscuring with a mix of HE and HC.

The smoke generator platoon begins to make smoke at H + 40 minutes at the LD. In addition, the flank security force on the eastern flank ignites and dumps its smoke pots within 500 meters of the LD.

At H + 40 minutes, the security force combat vehicles initiate screening smoke with their VEESS. The artillery and mortar units increase their rate of fire.

At H + 45 minutes, the main body crosses the LD. The main body maneuvers to the west of the smoke along the bypass route (Figure 7, on the next page).

Attack Phase

The movement to contact has developed into an actual engagement. The commander seizes the initiative and orders the brigade to attack toward Objective Fox. The main attack is in the west along Axis Andy. The supporting attack is in the east along Axis Tony. The brigade will consolidate on the objective and continue the attack towards the division objective.

At H + 46 minutes, the artillery shifts fire from the area between the CRP and FSE to the area between the FSE and advanced guard (AG), obscuring the target with a mixture of HE and HC. Also, the mortars shift fire from the CRP to between the CRP and FSE, obscuring with a mixture of HE and WP.

When the main attack has cleared the LD, the security force elements in the west turn off their VEESS. At the same time the supporting attack force engages the enemy FSE and AG with flanking fire.

At H + 50 minutes, the artillery shifts fire from the area between the FSE and AG to the area between the AG and the main body in the west, and onto the objective in the east. The artillery continues to fire a mix of HE and HC.

Also at H + 50 minutes, the mortars shift fire from the area between the CRP and FSE to the area between the FSE and AG, obscuring with a mix of HE and WP.

At the same time, the smoke platoon stops making smoke. This will ensure the objective itself is unobscured during the assault.

The main attack force is in position to make the assault on the objective at H + 55 minutes. The artillery shifts fire to the regimental main body beyond the objective, now firing only HE. The rnortars shift fire onto the AG in the center and in the west,

obscuring and isolating them with HE and WP mix.

At H + 1 hour, the main attack force assaults the objective. Artillery and mortars continue to fire on the enemy main body, isolating the objective from external Support.

Exploitation Phase

The enemy resistance is crumbling. 2d Brigade has significantly disrupted the enemy's synchronization and has the initiative. Upon securing the brigade objective, the brigade rapidly consolidates and the commander orders them to continue the attack. The brigade's follow-on objective is to secure Objective Jack and destroy the remnants of the enemy division artillery group (DAG). The main attack is in the east along Axis Stef, with the supporting attack in the center along Axis Gay.

At H + 1.25 hours, the mortars begin to fire on the remaining regimental main bodies, obscuring them with a mixture of HE and HC.

At the same time, the artillery begins to fire scatterable mines and HE and HC mix into the area behind the first-echelon regiments. This isolates the first echelon from the combined arms reserve and delays their retreat.

At H + 1.5 hours, the smoke platoon begins to make smoke in the west of the sector to isolate the remnants of the easternmost first-echelon regiments from the other first-echelon regiment. This further disrupts the enemy commander's synchronization, command, and control.

The main and supporting attack forces begun moving towards Objective Jack, keeping the enemy under pressure. They will bypass any enemy

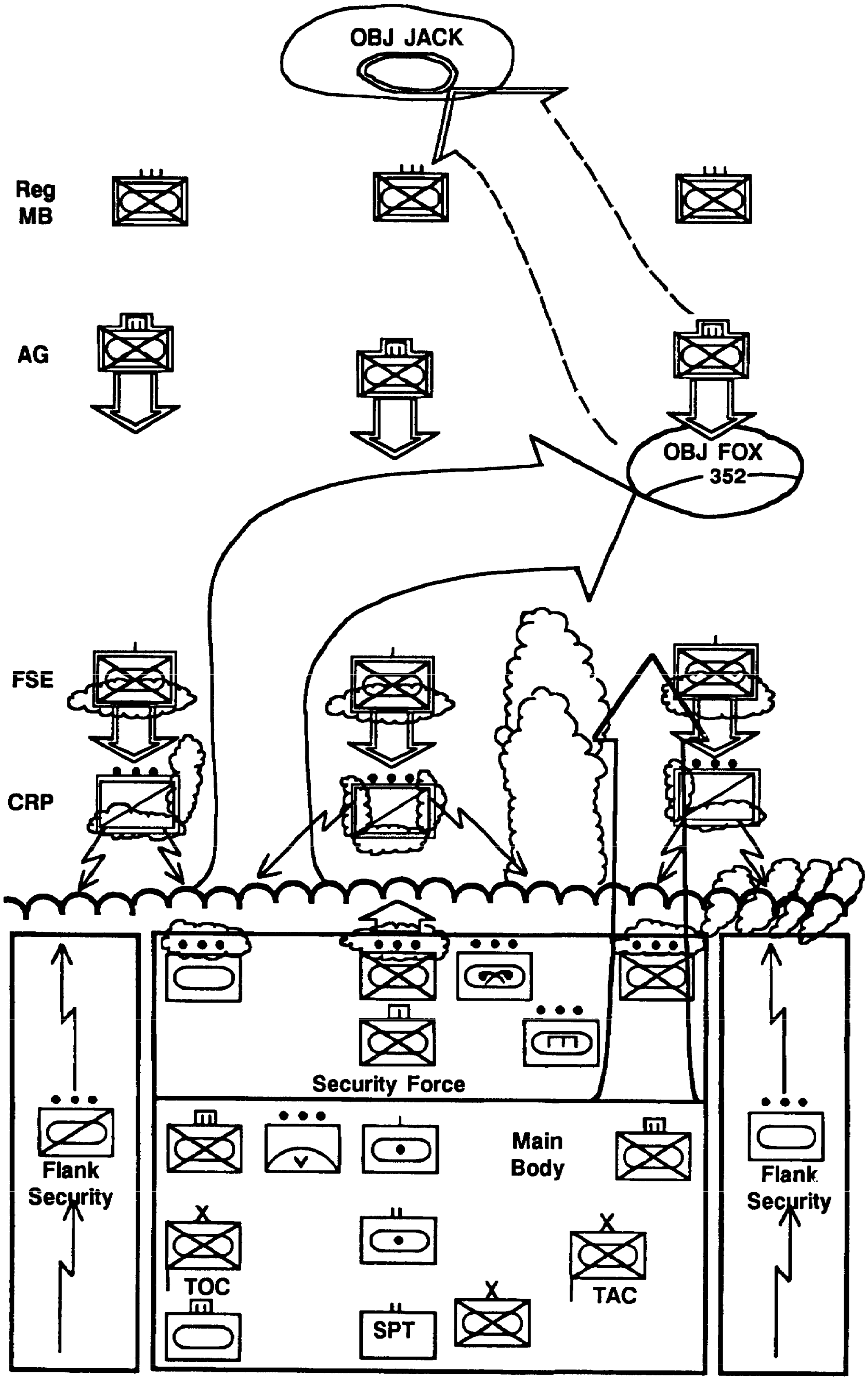

Figure 7. In this attack scenario, we are using the mechanized smoke platoon to produce a large-area smoke cloud to isolate enemy regiments in the east from each other. The security force vehicles use their VEESSs to conceal the movement of the main body behind the LD/LC. Projected smoke, fired at TAIs and known enemy positions, obscures enemy RSTA and protects the force as we begin to cross the LD/LC.

forces they encounter, with the brigade follow-on forces containing and destroying pockets of enemy forces bypassed by the main body.

At H + 1.75 hours, the mortars and arti!lery shift to fire behind the first-echelon regiments and onto Objective Jack, respectively. Both mortars and artillery will fire a mix of HE and WP for obscuration and lethality.

The mortars shift fire onto Objective Jack at H + 2 hours, and the exploitation force positions for the final assault on the objective.

At H + 2.10 hours, the mortars and artillery shift fire beyond Objective Jack. The main attack force assaults the objective, destroying the enemy DAG.

Pursuit Phase

By H + 2.25 hours, it is obvious that the enemy can no longer maintain their position, and 2d Brigade is capturing significant numbers of soldiers and equipment. The enemy resistance has crumbled. The enemy is now in full flight.

Upon securing the brigade follow-on objective, the brigade rapidly consolidates, and the commander orders them to conduct the pursuit. The direct pressure force moves rapidly forward along a!l available roads, bypassing small enemy pockets of resistance. The encircling force plans to move rapidly to the division objective and cut off the enemy retreat.

At H + 2.50 hours, aviation assets locate and mark the !arger enemy formations with WP rockets. The mortars and artil!ery assets with the direct pressure force then fire successive belts of scatterable mines behind these larger formations. They also fire HE and HC mix onto the formations to further slow them and complicate command and control.

At H + 2.75 hours, the encircling force leaves its assembly area, moving rapidly along the western flank towards the division objective. By H + 3.5 hours, the encircling force has bypassed and outdistanced the entire enemy formation. The encircling force commander now establishes a hasty defense, blocking the enemy's escape route.

At H + 3.75 hours, the smoke platoon starts its third mission. The smoke platoon begins to make a smoke curtain across the enemy's escape route, while the artil!ery and mortars from the direct pressure force stop firing smoke. This allows the direct pressure force to engage the enemy with direct fire weapons that are unobscured while concealing the encircling force's preparations.

At H + 4.25 hours, the enemy is forced into an engagement area between the direct pressure and encircling forces. The smoke from the smoke generator platoon silhouettes the enemy force for attack by the direct pressure force. At the same time, the encirling force is able to engage enemy forces through the smoke or as they emerge from the smoke on the other side. The enemy is destroyed and forced to surrender.

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Chapter 4

Defensive Operations

Defensive operations retain ground, gain time, deny the enemy access to an area, and damage or defeat attacking forces. Smoke and obscurant use multiplies the commander's ability to disrupt enemy attacks, seize the initiative, and project combat power at the critical time and place to defeat the enemy. Smoke and obscurant use will support any type of defensive operation. Used correctly it will overcome any initial advantage of the attacker.

Historical Perspective

During World War II, large-area smoke denied the Germans observation for directing accurate, indirect fire onto the US Fifth Army at Anzio. The 24th Decontamination Company landed at Anzio on D day, equipped with Ml smoke generators, M4 smoke pots, and eight Navy Besler generators.

On its first night ashore the unit smoked the beaches and anchorage. Within two days they had set up a smoke line nearly 2 miles long. As the beachhead forces expanded, other smoke troops, including a British unit and the US 179th Smoke Generator Company, moved to Anzio to increase the size of the cloud. Initially, smoke at Anzio was intended to be part of the antiaircraft screen. This included making smoke at night, when flares dropped by lead planes appeared to be extinguished as they dropped into the smoke.

The Fifth Army's VI Corps began an end run that bogged down. The Germans contained the beachhead from its establishment on 22 January 1944 until the Allied breakout the following May. Experience showed that a favorite enemy tactic was low-level bombing attacks at dawn and dusk. Consequently, it soon became standard practice to smoke the port at dawn and dusk and during red alerts for antiaircraft defense. The Luftwaffe made at least one raid each night until mid-February, when the artillery fire increased. The Allies used 8-inch howitzers to demolish farmhouses suspected of harboring German observers. They fired smoke from chemical mortars and small-caliber artillery onto nearby ridges and towers.

Yet, enemy observers had an unrestricted view of the entire harbor from the mountains in the background for pinpoint firing with long-range guns. Although the entire beachhead was within range of enemy guns, the Allies failed to obscure the beachhead itself in January and February. The air defense, artillery, and naval commanders were afraid that smoke on the beachhead itself would interfere with observation for friendly fire and with unloading the ships at anchorage. From 22 January to 10 February alone, the Allies took average daily losses of almost 28 tons of ammunition from enemy long-range fire and bombing.

To reduce these losses, the corps chemical staff and chemical unit commanders, with the approval of the VI Corps commander, MG Lucian K. Truscott, developed a new technique for use of the mechanical smoke generators. The technique resulted in the production of a light haze between the harbor and the front lines. The haze was thin enough to permit normal operations within it and thick enough to prevent German observation from the encircling hills.

On 18 March 1944, the 179th Smoke Generator Company moved from the harbor to forward positions. The smoke line formed a 15-mile arc around the port (Figure 8, on the next page), with 22 possible positions on land. Based on wind direction, 19 of those 22 positions had smoke generators. Also, two generators were mounted on Navy patrol craft in the harbor. The smoke generator positions were at 1,000-meter intervals just beyond the antiaircraft positions of the port and just short of the field artillery observation posts. The latter prevented enemy observation from the flanks of the concave harbor. The smoke sections began operations ½ hour before dawn and made smoke until 14 hour after sunset every day from 18 March until after the breakout in May 1944. During this period, the Allied troops at Anzio were able to unload an average of 3,500 tons of supplies daily.

The National Training Center (NTC) is an area where smoke employment is possible on a large force-on-force scale. Key insights from the NTC for the defense include the following

- Smoke compresses the battlefield with engagements fought at shorter range.
- We must use alternate weapon positions in smoke.
- Smoke employment requires more detailed planning.
- Smoke can be used in deception, at night, and for obstacle reduction.
- Units that do not train in smoke do not perform well.

Uses

Smoke and obscurants integrated throughout the defensive framework provide major disruptions to enemy synchronization providing windows of opportunity for our forces to seize the initiative and set the terms of combat. In the defense—

- Use smoke to support maneuver by–
  - – Concealing disengaging and moving forces.
  - – Slowing and disrupting enemy movement.
  - – Isolating attacking echelons.
  - – Concealing engineer operations and defensive preparations.

In addition, use the guidance in Chapter 3 for additional ways to support maneuver.

- Use smoke to provide additional firepower by disrupting enemy command and control and forcing the enemy to mass, thus providing a lucrative target. Other ways are identical to those in offensive operations. See Chapter 3.
- Use smoke to protect the force in the same way as in offensive operations. See Chapter 3.

In addition to the general techniques listed in Chapters 1 and 3, techniques to minimize interference in the defense include the following

- **Verify enemy locations** (responsibility of reconnaissance).
  - – The enemy can use both our smoke and theirs to conceal move-

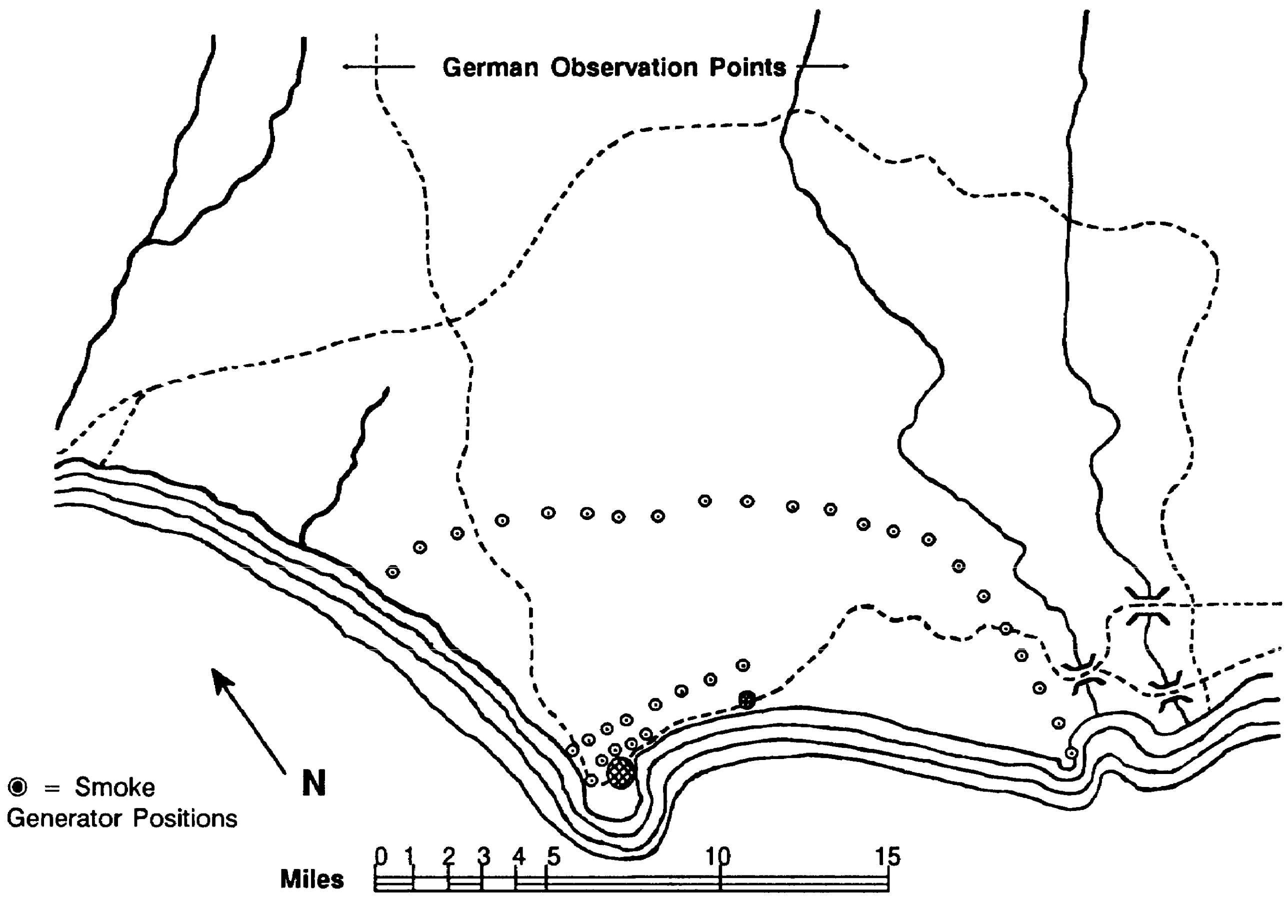

Figure 8. Smoke unit positions at Anzio Beachhead after 18 March 1944.

ment to alternate positions or to break contact.

– Aggressive reconnaissance before and during the engagement will allow you to shoot and remain in contact.

– You can use aviation assets to spot and mark enemy targets for destruction by indirect and direct fire.

- **Plan and use all sensor and viewer capabilities.** Consider placing ground surveillance radar, air defense weapons, and target acquisition radars on the flanks or high ground to acquire targets through the smoke. Maintain communications between these systems and both direct and indirect fire elements. Use the acquisition element to observe and adjust direct and indirect fire at targets.
- **Plan for enemy countermeasures.** Enemy forces will counter your smoke. The enemy may use countersmoke to confuse our command and control, so avoid reliance on visual signals. The enemy will increase use of indirect fire weapons when direct fire target acquisition is ineffective. Therefore, plan artillery counterbattery and countersmoke fire when you stop or delay the enemy.

Goal

As in offensive operations, the main focus of smoke in the defense is to defeat enemy target acquisition and reconnaissance, and to conceal maneuver and support forces. Our intent is to deny the enemy information about the disposition and composition of our forces. That allows us to gain time, concentrate forces elsewhere, control key or decisive terrain, and wear down enemy forces as a prelude to offensive operations.

Our overall goal is to improve the commander's ability to retain his initiative in operations against a potentially numerically superior force. Appendix A contains tactical decision aids for determining which smoke delivery means to use against the specific smoke targets covered by the tactics for using smoke in defensive operations.

Elements of Defense

The five complementary elements of the defense are deep operations forward of the FLOT, security force operations forward and to the flanks of the defending force, defensive operations in the main battle area (MBA), reserve operations in support of the main defensive effort, and rear operations.

Deep Operations

In the defense, deep operations are aimed at preventing the enemy from concentrating overwhelming combat power by disrupting their momentum and destroying the coherence of their attack. In deep operations, use smoke to —

- Force the enemy to deploy into our strength.
- Defeat or disrupt command and control efforts.
- Isolate reinforcing echelons from the assault force.

Smoke employment tactics in deep operations are identical to those in offensve operations (preparation phase). See Chapter 3.

Security Force Operations

The fundamental purposes of security force operations are to defeat and destroy enemy reconnaissance forces, force the enemy to deploy, confirm the direction and strength of the enemy attack toward the main body, and buy time for the main body to deploy forward and laterally. Use smoke in security force operations to—

- Conceal movement of maneuver and support forces, allowing the commander to mass forces unobserved.
- Provide tactical surprise, allowing the commander to seize the initiative and set the terms of combat.
- Defeat enemy reconnaissance and counterreconnaissance efforts.
- Conceal obstacle emplacement.

The first part of the defensive battle that the friendly commander must win is counterreconnaissance. Counterreconnaissance is an integral part of the security mission. The focus of the Threat's reconnaissance is to confirm or deny the dispositions and intentions of our force. Use smoke as an active counterreconnaissance measure to—

- Fix the enemy reconnaissance force.
- Mark the enemy reconnaissance force for destruction with direct and indirect fire weapons.
- Deny the enemy reconnaissance force information about the disposition, composition, or intent of friendly forces.

Smoke employment tactics in counterreconnaissance are the following:

- Screening smoke. Use screening smoke to conceal maneuver and obstacle emplacement. Use smoke in the security force area and along the flanks to conceal movement. Use smoke forward of the battle hand over line to allow the security force to disengage. You must carefully control the smoke to prevent silhouetting your units.
- Protecting smoke. Use protecting smoke to defeat enemy antitank and air defense systems.
- Obscuring smoke. Use projected smoke mixed with high-explosive rounds before the enemy can pinpoint your units. Plan obscuring fire based on decision points for the enemy to isolate and confuse their

reconnaissance forces. Plan obscuring fire during the battle hand over to allow the security force to disengage and pass through friendly lines unobserved.

- Marking smoke. Use marking smoke to mark enemy targets for rapid destruction or to reduce the potential for firing on friendly forces. Aviation reconnaissance assets are particularly useful to spot the reconnaissance force and mark it with helicopter-delivered smoke rockets.
- Smoke for deception. Uses are identical to those in offensive operations (preparation phase). See Chapter 3. Figure 9, below, shows smoke employment in security operations.

Main Battle Area

The decisive battle usually takes place in the MBA. The defender concentrates the strongest possible forces for decisive action against the enemy main effort. Use smoke to –

- Defeat enemy target acquisition efforts without degrading our own ability to acquire and engage.
- Create opportunities for commanders to seize the initiative locally and attack.
- Slow the advance of the attacking force.
- Separate and isolate the attacking echelons.
- Force enemy infantry to dismount.
- Disrupt the enemy's ability to exercise command and control.
- Once the enemy is in the engagement area of our choosing, prevent them from breaking contact so we can destroy them immediately.

Smoke employment tactics in the MBA are the following:

- Obscuring smoke. Use obscuring smoke to isolate the engagement area and counterattack or spoiling attack objectives, defeat enemy target acquisition and guidance systems, and defeat reconnaissance and counterreconnaissance efforts. Use projected smoke means to deliver smoke mixed with high-explosive rounds in front of the objective; between enemy formations; and on identified forward observer, ATGM, and tank unit positions before the enemy can pinpoint your units as targets. Using projected

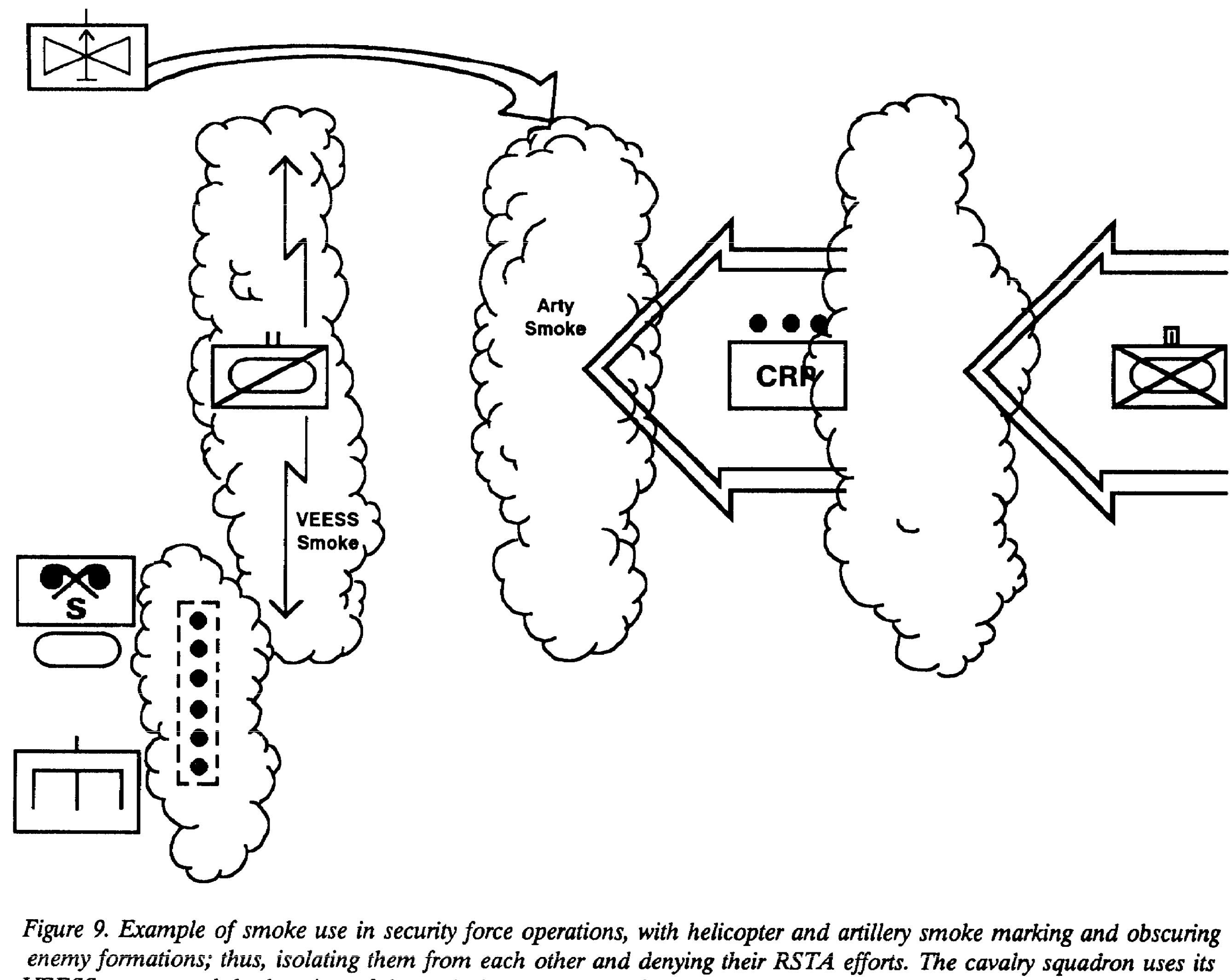

Figure 9. Example of smoke use in security force operations, with helicopter and artillery smoke marking and obscuring enemy formations; thus, isolating them from each other and denying their RSTA efforts. The cavalry squadron uses its VEESSs to conceal the location of the main battle positions from direct observation. Mechanized smoke assets conceal engineer obstacle emplacement, protecting that critical asset from interdiction.

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smoke as countersmoke and to isolate the objective can significantly interfere with the enemy commander's synchronization.

- Screening smoke. Use screening smoke to conceal maneuver as you move to new positions; conceal the force as you bypass, breach, or cross obstacles or small pockets of resistance in counterattack or spoiling attack; along the flanks to protect the force; and in the rear to conceal disposition and composition of reserves. Use self-defense and generated-smoke means to deliver smoke across danger areas and to the flanks of the force to limit enemy observation and engagement.
- Identifying smoke. Use the same technique as in the security force operations.
- Protecting smoke. If the enemy has known or suspected directed-energy weapon capability, concealing your force in a blanket of oil smoke will attenuate some of the energy.
- Smoke for deception. Use this smoke to draw attention away from the main defensive effort and the counterattack or spoiling attack to areas of little or no importance. Use generated-smoke to create small- to large-area smoke away from the main body.

Reserve Operations

The primary purpose of the reserves in the defense is to counterattack, to exploit enemy weaknesses, and to reinforce forward defensive operations. Use smoke in reserve operations to—

- Deny the enemy information about the location and strength of reserve forces.
- Conceal movement of reserve forces, allowing the commander to mass forces unobserved.
- Provide tactical surprise, allowing the commander to seize the initiative and set the terms of combat.

The employment tactics for smoke support in reserve operations depend on how, when, and where the commander chooses to use his reserves. In general, the tactics for smoke employment for reserves in a counterattack or spoiling attack role are the same as smoke tactics for the preparation phase of offensive operations. For reserve forces in a reinforcing role, the smoke tactics are the same as those for security force operations in the defense.

Rear Operations

We conduct rear operations to allow the commander freedom of maneuver and for continuity of operations, to include continuity of sustainment functions and command and control. Use smoke in rear operations to—

- Conceal support forces, facilities, and activities. Reducing enemy observation reduces the necessity to move frequently. When necessary, conceal movement of support forces.
- Deny the enemy use of landing zones and/or drop zones.
- Isolate enemy forces in the rear area.
- Defeat rear area Threat acquisition efforts and support base, base cluster, and rear operations response to the Threat.

Smoke tactics in rear operations are also dependent upon the commander's intent and the threat. In general, use smoke to attack enemy target acquisition and engagement efforts when identified. The smoke employment tactics are similar to those for a hasty attack. Figure 10, on the next page, illustrates smoke use in rear area operations.

Example

The following example depicts a mechanized infantry heavy brigade conducting the movement to contact. The brigade is the 2d Brigade, 54th Infantry Division (M). Smoke delivery means include the direct support artillery battalion, battalion mortars, smoke generator platoon, VEESS, smoke pots, smoke grenades, and aviation assets on-call. 2d Brigade will defend in sector, commencing at H-hour. The commander's intent is to force the enemy to deploy prematurely, seize the initiative, and conduct local counterattacks to destroy the enemy force.

Intelligence indicates the enemy is the 1st Guard Motorized Rifle Division, 2d Combined Arms Army, which relieved another motorized rifle division and is conducting a meeting engagement from the march. The enemy is marching by regiments, with three rrgiments in front and a combined arms reserve instead of a second echelon. Terrain is fairly open to the west of Hill 268 but is restricted to the east of Hill 352. The enemy has excellent observation and fields of fire from both hills.

At H – 48 hours, the commander issues the restated mission and his planning guidance. The brigade chemical officer, S2, and FSO go to the intelligence cell and begin target development.

The brigade chemical officer has completed his estimate at H – 42 hours and provides a draft target list to the FSO. While the brigade chemical officer briefs the commander, the brigade chemical NCO continues smoke target analysis in coordination with the smoke platoon leader.

At H -36 hours, the brigade chemical officer, FSO, and smoke platoon leader finalize the smoke support plan. This includes a draft smoke support annex to the brigade OPORD.

At H -33 hours, the brigade commander approves the final OPORD. The brigade commander and staff issue the order to the commanders and specialty unit leaders.

Three hours later, the smoke platoon makes smoke to conceal obstacle emplacement.

At H – 24 hours, the brigade chemical officer finalizes smoke support coordination with all units. This includes coordination with adjacent units that might be affected by smoke if the wind shifts.

At H – 20 hours, the brigade chemical NCO verjfies with the FScell that the additional smoke munitions for the artillery and mortars are on hand and prepositioned.

The brigade chemical officer receives a brief back from the smoke platoon leader and assistant S3 (operations) officer at H -18 hours. These officers verify rehearsals in the smoke platoon and maneuver units (for on-board smoke use). The FScell and chemical cell also check communications circuits at this time.

At H – 15 hours, aviation reconnaissance spots enemy divisional reconnaissance assets. Helicopter-delivered rockets mark this enemy element for destruction by CAS aircraft.

At H – 12 hours, the security force encounters enemy reconnaissance assets. Based on the commander's decision support template, the DS artillery battalion begins to fire a mixture of HE and smoke (HC) onto identified targets. Mortars moving with the security force also fire a mixture of HE and smoke (WP) between the security force and the reconnaissance assets. This will deny the enemy information and confuse them as to the location and disposition of our force.

Thirty minutes later, the security force engages the enemy reconnaissance with direct fire weapons. Artillery and mortar fire shift to behind the enemy reconnaissance force. This shifting of fire silhouettes the enemy, isolates the enemy, and prevents obscuration of our own direct fire

At H – 8 hours, the security force identifies elements of the enemy FSE moving into the brigade area of operations. Aviation and artillery assets mark targets with WP for attack by CAS aircraft.

The security force, at H – 6 hours, identifies elements of the enemy AG moving into the brigade area of operations. The smoke platoon stops smoke at the obstacle emplacement.

At H – 2 hours, the security force begins to withdraw. Security force mortars fire HE and WP mix to allow the security force to disengage. The smoke platoon makes smoke at the battle hand over line to conceal the rearward passage of lines.

At H-hour, aviation reconnaissance identifies elements of the division main body entering the brigade area of operations. The security force has done its job and forced the enemy to deploy along the western approach, avoiding the high ground on Hill 352. The artillery begins to fire on the flanks and forward elements of the enemy AG and main body. The mortars begin to fire on the flanks and forward elements of the enemy FSE. Both use a mixture of HE and WP. This will isolate the enemy forces and serve as good reference points for adjusting indirect and direct fire.

At H + 30 minutes, the enemy main body has entered the engagement area. Our indirect fire has caused attrition to their FSE and A G and forced the main body into our strength. The brigade commander now orders the artillery to fire FASCAM mixed with HC behind the engagement area to delay reinforcements and to isolate the main body for destruction.

At H + 1 hour, the direct fire fight has begun. Artillery fire switch to HE and HC mix. Mortars fire HE onto the enemy and WP onto the flanks. Our GSR teams pass target acquisition information to the TOW sections of each company. Our forces use thermal sights to acquire and engage the enemy, who cannot see through the smoke.

By H + 2 hours, the enemy commander is unable to maintain his momentum and begins to withdraw.

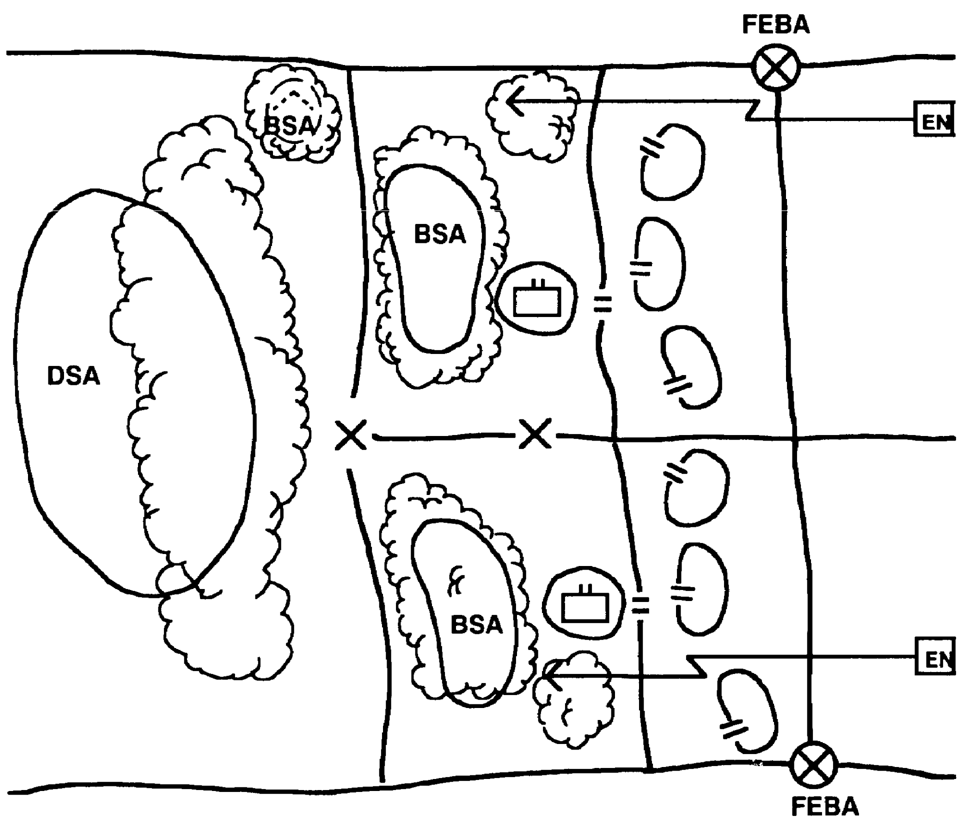

Figure 10. This example of smoke employment in rear operations uses large-area smoke clouds to conceal support activities from enemy RSTA efforts. A dummy BSA also has smoke support to complicate enemy intelligence gathering and to make our deception plan more believable. If enemy forces penetrate to our rear area, a mixture of HE and WP will delay their movement and mark them for destruction by responding forces.

Chapter 5

Other Tactical Operations

Other tactical operations cover a wide range of special-purpose operations undertaken routinely during offensive and defensive operations. While these operations are not the main focus of the commander at the tactical level of war, smoke may support these operations as well. These operations include–

- Retrograde operations.
- Relief-in-place operations.
- Passage of lines.
- Linkup operations.
- Breakout from encirclement.
- River crossings.
- Obstacle breaching.

In addition, there are special conditions and environments we must consider:

- Mountains.
- Jungles.
- Urban terrain.
- Deserts.
- Winter zones.
- Nuclear, biological, and chemical (NBC) conditions.

Finally, because smoke draws attention, we must consider smoke support for tactical deception.

Tactics

Smoke and obscurants integrated throughout the battlefield and operational continuum provide major contributions to combat power in deep, close, and rear operations. In other operations, the major contributions are the same as those in offensive smoke tactics. See Chapter 3.

Smoke and obscurant use in other tactical operations requires the same careful planning and execution as with the offense and defense. In addition to the general techniques listed in Chapter 3, special techniques to minimize interference include –

- **Know the limitations of your delivery systems.** Smoke munitions do not behave the same in all conditions or environments (for example, the jungles of Central America versus the woodlands of Europe). Plan for differences in coverage. Some munitions combinations such as HE and WP are not effective under certain environments or conditions such as winter zones with deep snow.
- **Use smoke to mask terrain from aerial observation.** With the exception of jungles, much of the terrain described in this chapter affords good aerial observation. By masking key terrain features you reduce your vulnerability as targets of opportunity for high-performance aircraft.

Retrograde

A retrograde operation is a movement to the rear or away from the enemy.

Retrograde operations gain time, preserve forces, avoid combat under undesirable conditions, or draw the enemy into an unfavorable position. In retrograde operations–

- Use smoke to support maneuver by–
  – Concealing maneuvering forces from enemy observation.
  – Concealing disengaging and moving forces.
  – Providing tactical surprise and allowing the commander to set the terms of combat.
  – Allowing the commander to mass forces unobserved.
  – Defeating enemy surveillance efforts.
  – Supporting the deception story.
  – Slowing and disrupting enemy movement.
  – Isolating attacking echelons.
  – Concealing engineer operations defensive preparations to the rear
- Use smoke to provide additional firepower by–
  – Defeating enemy counterreconnaissance efforts.
  – Disrupting enemy command and control.
  – Disrupting enemy maneuver and reinforcement.
  – Disrupting the enemy's ability to communicate.
  – Forcing the enemy to mass, thus providing a lucrative target.
  – Changing friendly to enemy force ratios by using thermal imagers and

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millimeter wave acquisition devices such as radars to see through visual smokes and using smoke to isolate defending and second-echelon forces.

– Enhancing friendly target acquisition efforts by silhouetting enemy vehicles with smoke and using smoke and obscurants we can see through but the enemy cannot.

- Use smoke to protect the force. (See Chapter 3 under Offensive Smoke Tactics.)

Delay

In delays, units give ground to gain time. Delaying units inflict the greatest possible damage on the enemy while preserving their freedom of action.

In the delay, use smoke to–

- Conceal movement of maneuver and support forces, allowing the commander to mass forces unobserved.
- Provide tactical surprise, allowing the commander to seize the initiative and set the terms of combat.
- Defeat enemy reconnaissance and counterreconnaissance efforts.
- Conceal obstacle emplacement, breaching, or crossing.
- Conceal designated withdrawal routes.
- Maintain contact with the enemy but preclude decisive engagement.

Smoke employment tactics in the delay are the following:

¤ **Screening smoke.** Use screening smoke to conceal maneuver and obstacle emplacement. Use smoke along withdrawal routes and along the flanks to conceal movement. Begin making smoke prior to departing your existing position to confuse the enemy as to the actual location and size of the force. Use projected means to deliver smoke between the delaying unit and the enemy force. Use smoke to conceal obstacle breaching or crossing. The priority of effort is to mobility operations; therefore, carefully control the smoke to prevent slowing or silhouetting your units.

- Protecting smoke. Use protecting smoke as required to defeat enemy ATGMs and air defense systems. Use protecting smoke to avoid decisive engagement.
- Obscuring smoke. Use obscuring smoke to defeat enemy reconnaissance and counterreconnaissance efforts. Use projected smoke means to deliver smoke mixed with high-explosive rounds before the enemy can pinpoint your units. Attempt to force the enemy into early deployment.
- Marking smoke. Use marking smoke to mark enemy targets for rapid destruction or to reduce the potential for firing on friendly forces.
- Smoke for deception . Use supporting smoke to draw attention to areas of little or no importance. Create large-area smoke away from the delaying force. Consider using smoke mixed with high-explosive rounds to conduct preparatory fire of dummy objectives.

Withdrawal

In withdrawals, a force in contact disengages from the enemy. The force may be assisted by another force or unassisted. In the withdrawal, use smoke to–

- Conceal movement of maneuver and support forces, allowing the commander to mass security forces unobserved.
- Defeat enemy reconnaissance and counterreconnaissance efforts.
- Conceal obstacle emplacement, breaching, or crossing and hinder pursuit by the enemy.
- Conceal designated withdrawal routes, traffic control points, and on-order assembly areas.
- Create opportunities to disengage the force.

Smoke employment tactics in the withdrawal include the following:

- Screening smoke. The tactics are the same as those under Delay. Additionally, use projected means to deliver smoke between the security force and the enemy force.
- Protecting smoke. The tactics are the same as those under Delay.
- Obscuring smoke. The tactics are the same as those under Delay.
- Marking smoke. The tactics are the same as those under Delay.
- Supporting smoke for tactical deception. Use supporting smoke to draw attention to areas of little or no importance. Create large-area smoke away from the main body.

Retirement

In a retirement, a force not in contact moves away from the enemy in an organized manner. In a retirement, a heavy rear guard will conduct delaying actions to slow the advance of the enemy and allow the main body to increase the distance between itself and the enemy. In general, use smoke to support the rear guard in its delaying operations. The tactics for employment of smoke in support of the rear guard are the same as for the delay.

Relief in Place

In a relief in place, a unit in contact is replaced by another that assumes the missions of the outgoing unit. Use smoke to–

- Fix the enemy reconnaissance force.
- Mark the enemy reconnaissance force for destruction with direct and indirect fire weapons.
- Deny the enemy reconnaissance force information about the disposition, composition, or intent of friendly forces.
- Conceal the movement of relieving forces. This is critical as dispersion of forces in a relief is difficult. The enemy may exploit the massing

as a time to attack with NBC weapons.

A special consideration for reliefs is to maintain the illusion the force has not changed. Obtain the relieved force's smoke annex. In planning the relief, attempt to duplicate patterns of employment for a brief period.

Smoke employment tactics in a relief in place are the following:

- Screening smoke. Use screening smoke to conceal maneuver. Use smoke in the reserve force area and along the flanks to conceal movement. Use smoke forward of the FLOT to allow the relieved force to disengage. You must carefully control the smoke to prevent silhouetting your units.
- Protecting smoke. Use protecting smokes to defeat enemy antitank and air defense systems.
- Obscuring smoke. Use projected smoke means to deliver smoke mixed with high-explosive rounds before the enemy can pinpoint your units. Plan obscuring fire based on decision points for the enemy, isolating and confusing their reconnaissance forces. Plan obscuring fire during the relief to allow the relieved force to disengage and pass through friendly lines unobserved.
- Marking smoke. Use marking smoke to mark enemy targets for rapid destruction or to reduce the potential for firing on friendly forces. Use aviation reconnaissance assets to spot the enemy reconnaissance force and mark it with smoke rockets.
- Supporting smoke for tactical deception. The tactics are the same as in the withdrawal phase.

Passage of Lines

A passage of lines is a coordinated movement of one or more units through another unit. Units conduct passage of lines to continue an attack or counterattack, envelop an enemy force, pursue a fleeing enemy, or withdraw a security or main battle force. Synchronization is the overriding imperative. Use smoke to—

- Conceal movement of maneuver and support forces, allowing the commander to mass forces unobserved.
- Provide tactical surprise, allowing the commander to seize the initiative and set the terms of combat.
- Defeat enemy reconnaissance and counterreconnaissance efforts.
- Conceal obstacle breaching or bypass.

Smoke employment tactics in passage of lines are the following:

- Screening smoke. Use screening smoke to conceal maneuver and obstacle breaching. Use smoke at the contact point, along passage lanes, and along the flanks to conceal movement. Use smoke forward of passage points. You must carefully control the smoke to prevent silhouetting your units.
- Protecting smoke. Use smoke to defeat enemy antitank and air defense systems.
- Obscuring smoke. Use projected smoke means to deliver smoke mixed with high-explosive rounds before the enemy can pinpoint your units. Plan obscuring fire based on decision points for the enemy, isolating and confusing their reconnaissance forces. Plan obscuring fire during the passage of lines to allow the force to pass through friendly lines unobserved.
- Marking smoke. The tactics are the same as those under Relief in Place.
- Supporting smoke for tactical deception. Use supporting smoke to draw attention to areas of little or no importance. Create large-area smoke away from the main body. Consider using smoke mixed with high-explosive rounds to conduct preparatory fire of dummy objectives.

Linkup Operations

Two friendly forces are joined in linkup operations. Units conduct linkup operations to complete an encirclement of an enemy force, assist in breakout of an encircled friendly force, or to join an attacking force with a force inserted into the enemy rear.

Use smoke to–

- Mark the coordinated fire line (CFL) or the restrictive fire line (RFL) to prevent fires being set by friendly forces.
- Conceal movement of the linkup force.
- Deny the enemy information concerning when and where the linkup will occur.

Smoke tactics for linkup operations are the following:

- Obscuring smoke. The tactics are the same as those for the exploitation phase of offensive operations (Chapter 3).
- Screening smoke. Use screening smoke to conceal maneuver and support forces and defeat enemy target acquisition and guidance systems. Use self-defense and generated-smoke means to conceal maneuver units as they bypass or harass enemy forces.
- Marking smoke. Use marking smoke to mark the CFL or RFL, mark targets for destruction, identify bypass routes, and signal for battlefield activities. Use projected smoke means to deliver smoke onto identified enemy strongpoints or larger formations and to signal forces to consolidate on a particular objective or rally point.
- Protecting smoke. If the enemy has known or suspected nuclear or directed-energy weapon capability,

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concealing your logistics activities in oil smokes may attenuate some of the energy.

- Smoke for deception. Use this smoke to keep the enemy off-balance and to draw attention away from critical sustainment activities.

Breakout from Encirclement

A breakout from encircled forces differs from other attacks only in that units must maintain a simultaneous defense of other areas of the perimeter.

Use smoke to–

- Aid in establishing a deception story.
- Isolate and segregate enemy forces to create gaps or weaknesses in the encircling force.
- Conceal movement of maneuver and support, allowing the commander to mass the rupture force and main body unobserved.
- Defeat enemy reconnaissance and counterreconnaissance efforts.
- Conceal obstacle emplacement, breaching, or crossing and hinder pursuit by the enemy.
- Create opportunities to disengage the force.

Smoke employment tactics in breakout from encirclement include–

- Obscuring smoke . Use obsuring smoke to isolate the rupture objective, defeat enemy target acquisition and guidance systems, and defeat reconnaissance and counterreconnaissance efforts. Use projected smoke means to deliver smoke mixed with high-explosive rounds in front of the objective; between enemy formations; and on identified forward observer, ATGM, and tank unit positions before the enemy can pinpoint your units as targets.
- Screening smoke. Use screening smoke to conceal maneuver as you bypass, breach, or cross obstacles or small pockets of resistance, along the flanks to protect the force, and in the rear to conceal disposition and composition of both the reserves and rear guard. Use self-defense and generated-smoke means to deliver smoke across danger areas and to the flanks of the force to limit enemy observation and engagement.
- Marking smoke. Use marking smoke to mark enemy targets for rapid destruction or to reduce the potential for firing on friendly forces.
- Protecting smoke. If the enemy has known or suspected directed-energy weapon capability, concealing your force in a blanket of oil smoke will attenuate some of the energy.
- Smoke for deception. Use this smoke to draw attention away from the main effort to areas of little or no importance. Since the diversionary force is critical to the breakout, consider making it the priority for smoke support. Use generated-smoke means to create small- to large-area smokes away from the main body.

River Crossings

Units conduct river crossings as part of a higher headquarters scheme of maneuver. The commander's objective is to project his combat power to the exit side of the river quickly to maintain the unit's momentum. The overriding imperative is synchronization. Effective command and control are critical for success. Apply all techniques to minimize the interference caused by smoke. Use smoke to–

- Conceal the movement of the initial assault force.
- Isolate the exit bank of the river for rapid occupation by maneuver forces.
- Conceal emplacement of crossing means such as engineer bridges.
- Isolate follow-on objectives to allow the commander to rapidly project combat power across the river.

Smoke employment tactics in river crossings include—

- Screening smoke. Use screening smoke to conceal maneuver and actual river crossing sites. Use smoke in the main body area and along the flanks to conceal movement. You must carefully control the smoke to prevent silhouetting your units. Begin making smoke prior to conducting the initial assault to confuse the enemy as to the actual location and size of the force. Use projected-smoke means to deliver the initial screening smoke to isolate the exit bank objectives and give other smoke delivery means time to build effective smoke.
- Protecting smoke. Use protecting smoke as required to defeat enemy ATGMs and air defense systems.
- Obscuring smoke. The tactics are the same as in the preparation phase for offensive operations (Chapter 3).
- Marking smoke. Use marking smoke to mark enemy targets for rapid destruction or to reduce the potential for firing on friendly forces. Aviation assets can deliver smoke onto identified enemy positions for destruction by indirect fire or the follow-on force.
- Smoke for deception. The tactics are the same as in the preparation phase for offensive operations (Chapter 3).

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Obstacle Breaching

Units breach obstacles when they cannot bypass them at an advantage. The commander's objective is to project his combat power to the exit side of the obstacle quickly to maintain the unit's momentum. The overriding imperative is initiative. In general, platoons and larger formations breach obstacles, with most smoke planning consisting of immediate fire requests for covert or hasty breaches or detailed planning for all potential smoke assets in deliberate breaches.

Use smoke to—

- Isolate the exit side objective.
- Conceal movement of the breaching, initial assault, and support forces.
- Conceal emplacement of crossing means such as engineer bridges or demolitions.
- Isolate the exit side of the obstacle for rapid occupation by maneuver forces.
- Isolate follow-on objectives to allow the commander to rapidly project combat power across the obstacle.

Smoke employment tactics for breaching include–

- Screening smoke. The tactics are the same as those under River Crossings.
- Protecting smoke. Use protecting smokes as required to defeat enemy ATGMs and air defense systems.
- Obscuring smoke. The tactics are the same as in the preparation phase for offensive operations (Chapter 3).
- Marking smoke. The tactics are the same as those under River Crossings.
- Smoke for deception. The tactics are the same as in the preparation phase for offensive operations (Chapter 3).

Special Conditions or Environments

Weather and terrain have a significant impact on smoke employment as previously stated. The following paragraphs present special climate considerations, employment tactics, and techniques to overcome difficulties under these conditions:

- Mountains.
- Jungles.
- Urban terrain.
- Deserts.
- Winter zones.
- Nuclear, biological, or chemical (NBC) conditions.

Mountains

In combat operations, mountains generally are characterized by rugged, compartmented terrain; steep slopes; and few natural or man-made lines of communication. The weather spans the entire spectrum from extreme cold, with ice and snow during winter, to extreme heat in some areas during summer. Although these extremes are important planning considerations, the variability of weather over short periods of time, and from area to area, also significantly influences maneuver, fire support, and smoke support operations.

Delivery Means

Mountainous terrain is generally hard and rocky in the summer with intermittent areas of deep snow. In the winter, the terrain is mostly covered with deep snow.

- Snow. The phosphorus in WP can burn undetected in snow for up to four days.
- Rocky terrain. Smoke is effective to deny the enemy the use of narrow passages, valleys, roads, and usable terrain.
- Winds. Swirling winds make smoke employment very difficult to adjust and maintain. Close coordination is required with adjacent elements to ensure that their vision is not obscured or they are not highlighted.
- Adjusting fire. Distances are difficult to judge. Observers tend to underestimate upslope distances and overestimate downslope distances.

Problems

Mortars are ideal because of their high-angle fire. They can deliver fire on reverse slopes and over intermediate crests.

Position observers on high ground and spread them to overcome terrain masks and compartments. Observers may require mountaineering equipment to get to the best positions, or they may be airlifted. Terrain sketches and visibility diagrams are essential to deliver fast, accurate fire and to identify blind spots.

Use ground surveillance radars and remote sensors to acquire targets. Use smoke to—

- Deny enemy use of narrow passages, valleys, roads, and usable terrain.
- Isolate enemy formations for piecemeal destruction.
- Obscure routes that can be used by the enemy to attack, withdraw, and resupply.
- Obscure likely position areas for indirect fire assets, command and control elements, CSS assets, and observation posts.
- Conceal terrain that is subject to snowslides, flash floods, and rockslides.

Jungles

Usually, jungle operations are carried out by light forces that can get into and out of areas by helicopter. Fire support may be limited to indirect fire and air support. Because small-unit operations are com-

monplace, greater challenges accrue to the chemical officers and fire support coordinators (FSCOORDs) at lower levels such as the company FSO and the battalion chemical officer.

Delivery Means

In jungle terrain, most contact with the enemy will be at extremely close ranges. If the friendly force has a substantial advantage in fire support, the enemy will most likely try to come in as close as possible and maintain that close contact so that the friendly force cannot employ their fire support advantage without inflicting casualties on their own troops.

In the triple-canopy jungle, HC smoke is ineffective. WP is effective as a marking round and in initial adjustments. ICM and FASCAM will hang up in the trees and endanger friendly forces that later move through the area. Illumination rounds are ineffective because the chutes get caught in the upper canopy.

The triple-canopy jungle makes observation beyond 25 to 50 meters very difficult. The jungle also makes map reading and self-location, target location, and friendly unit location determinations very difficult.

Problems

Experience from World War II and Vietnam showed that observers and smoke control officers must be able to adjust smoke and mortar and field artillery (FA) fire by sound because they often cannot see the rounds to adjust them. This sound adjustment is very difficult and requires wide experience.

By taking the recommended adjustments of two or more observers in different locations, some accuracy can result. The battery fire direction center (FDC) can help by announcing SPLASH to let the observer know when the round should impact. The observer then counts the seconds until he hears the round detonate. Multiplying the seconds by the speed of sound, the observer can estimate the range to impact. The speed of sound is approximately 350 meters per second. The speed of sound varies according to temperature, wind speed and direction, relative humidity, and air density; but 350 meters per second should be used as a start point.

The observer and smoke control officer must determine their locations and ensure that the TAC CP and FDC have them plotted. If the observer or smoke control officer's initial position locations are way off, the smoke will be way off too. Use the initial smoke to determine the observer's own location.

Vietnam and World War II also showed that the first projected round in adjustment must be WP smoke. Because the observers are not sure of their own location or that of other friendly elements, WP was always fired first to avoid inflicting casualties on friendly personnel.

Creeping fire was also used extensively in Vietnam and World War II. The observer adds 300 to 400 meters to his target location in case his own position location is wrong. Then he makes corrections of no more than 50 meters until the fire is on target. In Vietnam, this process sometimes started with an aerial observer and was taken over by the ground observer once he was able to see the rounds. The aerial observer was often required to relay fire requests from the ground because the terrain severely limited the ranges of radio communications.

Because of the close combat, laser range finders may not be of great use; however, night vision devices are extremely critical. Avoid using projected smokes during limited visibility periods to preclude degradation of these devices. Aerial observers help direct CAS assets against enemy targets. Because ground observers cannot see the whole battlefield, the aerial observer marks targets for the CAS sortie (flares, WP, smoke). Radars are extremely effective in the jungle, since most indirect fire is high-angle fire. Ground surveillance radars and remote sensors must be used.

Use smoke—

- To conceal maneuver to the front, flanks, and rear.
- Along roads and trails to deny enemy use.
- At likely ambush sites to obscure enemy observation and fields of fire.

Urban Terrain

In urban terrain, ranges are drastically reduced. There are three major types of terrain in nearly every built-up area:

- Obstructions, such as buildings and heavily wooded parks.
- Flat, open terrain over water, such as rivers and lakes.
- Flat, open terrain over concrete or asphalt, such as parking lots, multiple-lane roads and highways, and open lots.

Air currents are unpredictable. Obstructions tend to break up smoke streamers, which re-form into a more uniform cloud. Convection currents over open areas cause smoke to rise. There are many observation points at multiple levels, which allows an enemy to observe from either above or below smoke.

Delivery Means

Downwind coverage is often less due to obstructions breaking up the smoke, unpredictability of air currents, and smoke following street patterns. The Berlin Brigade observed that open areas in cities tend to cause smoke to rise and obscure key observation points. This is a particular problem over water, garden plots, and wide expanses of concrete.

Smoke diffuses well at night but tends to rise to rooftop level about one hour after sunrise until one hour after sunset. Burning rubble degrades the screening efficiency of smoke. Smoke pots weigh between 27.5 and 33 pounds (M4/M5), making it difficult for infantry squads to employ without transportation assets to move them forward first.

Smoke hand grenades make smoke for only 60 to 150 seconds. Squads need to carry four to six per person for concealment. Because of the height and closeness of buildings and other obstructions, CAS and artillery fire is degraded. Mortars and high-angle artillery are still effective.

Problems

Smoke and obscurant use in military operations on urbanized terrain (MOUT) requires careful planning and execution to prevent interference with movement, assault operations, or target acquisition; to retain the element of surprise; and to avoid silhouetting or drawing undue attention to friendly forces.

Time smoke delivery with decision points. Conduct a thorough IPB and time your use of smoke to key decision points in your tactical plan: for example, "When we reach Sector Al, use grenade launchers to smoke the open area and conceal movement of B Company as they emplace smoke pots.") Ensure you target key terrain to deny the enemy the use of it.

Use unobscured weapons to overwatch. The overwatching elements should have target acquisition devices such as thermal imagers that can see through our own smoke and engage the enemy. This prevents surprise and enhances your ability to suppress enemy fire during the assault. This is particularly important for observers in upper floors of buildings, enabling them to observe enemy movements while friendly forces move unobserved.

Limited visibility positions, preplanned and previously prepared, will minimize degradation caused by friendly or Threat use of smoke. Rehearsal of displacement under smoke will help you avoid confusion and disorientation. It will also rapidly restore engagement capability.

The best tactical application of smoke in urban areas is smoke blankets for concealment. Use smoke blankets prior to assaults. Sweep and clear operations to eliminate enemy forces acquiring our soldiers as targets. This is exceptionally effective in reducing or eliminating sniper activity and in breaching obstacles. However, your soldiers must be careful to avoid burning debris since this tends to reduce concealment.

Plan for enemy countermeasures. Enemy forces will counter your smoke use. Plan to intensify your counterreconnaissance and air defense efforts. The enemy may use countersmoke to confuse our command and control so avoid reliance on visual signals.

The enemy will increase use of indirect fire weapons when direct fire target acquisition is ineffective. Therefore, plan artillery counterbattery or countersmoke fire after crossing the LD/LC.

Reconnaissance must verify enemy locations. The enemy can use both our smoke and theirs to conceal movement to alternate positions or to break contact. Aggressive reconnaissance before and during the engagement will allow you to shoot and remain in contact.

Understand that smoke compresses the battlefield by limiting visibility. Smoke drastically reduces engagement ranges. Training your soldiers to operate in smoke reduces the degradation caused by smoke. It also reduces psychological impact on troops such as confusion, fear, and isolation. The Israeli Army successfully used phosphorous rounds in Beirut to screen their forces and isolate the enemy (enemy forces tended to congregate in the city). The use of smoke produced enemy casualties and generated the psychological effects of fear and isolation.

Urban terrain causes smoke streamers to break up quickly, creating the uniform phase closer to the smoke source. You can place smoke sources closer to target areas.

Ensure the entire squad, section, or platoon uses the smoke simultaneously to preclude drawing attention to a lone vehicle or element.

Smoke pots and smoke grenades are effective for concealing movement of small units. An example of an employment scenario follows:

Squad members come under fire from snipers in upper floors. They use a grenade launcher to fire smoke and HE rounds into upper floors, blinding enemy observation. They emplace HC smoke pots or several smoke hand grenades downwind of and in between themselves and the target area or building. Concealed by the smoke, they maneuver to assault the target. Upon reaching the target area, they cease to make smoke to allow them to operate undegraded.

Start the smoke mission prior to operation start time and continue well beyond the end of the operation. For example, you have planned a canal crossing for 0500 to 0700 hours. Start smoke at 0400. Stop smoke at 0800 to confuse the enemy as to the exact crossing time and size of the force.

Built-up areas nearly always have civilians/noncombatants occupying them. When planning the type of smoke weapon system, and you suspect noncombatants are present, give consideration to the lethality of the system before employment. For example, artillery-delivered smoke is useful around the periphery of a city. However, you should switch to less devastating systems in the center of the city, such as smoke munitions from grenade launchers, smoke pots, and smoke hand grenades.

Smoke units are extremely vulnerable in urban areas due to smoke generator signature. In addition, stationary smoke positions need to be closer to the target than over other terrain, bringing smoke generator elements within range of enemy small arms weapons. Mobile smoke systems are best. Stationary smoke systems make large volumes of smoke but require additional security support. Employ smoke generator vehicles in groups of three, with two vehicles making smoke and one vehicle overwatching.

Deserts

There are three types of deserts:
- Rocky plateau deserts.
- Sandy or dune deserts.
- Mountain deserts. (Munitions effectiveness for mountain deserts is the same as for any mountainous region except that the considerations of snow are usually not applicable.)

It is important to recognize the specific terrain of each, because munitions effects will vary according to desert type. Desert battles tend to be more centralized. Brigade and battalion commanders often personally coordinate the interaction of maneuver and firepower. Engagements are often fought at long ranges.

In rocky plateau deserts, projected smoke and illumination rounds may be degraded by high winds, but may be used to silhouette the enemy. HE/PD is extremely effective, creating extra shrapnel by splintering rocks. FASCAM is very effective and should be employed with smoke and the natural terrain to force the enemy into unnavigable terrain.

In sandy or dune deserts projected smoke and illumination rounds are effective and can be used to silhouette the enemy. HE, PD, ICM, FASCAM, and delay are smothered by deep sands, making them ineffective.

Location determination is often very difficult in rocky plateau and sandy or dune deserts. Maps are often inaccurate, dunes shift, and heat waves hamper distance estimations. The Israelis help forward elements determine their own location by using artillery survey teams at two or more points, putting searchlights on those points, and, upon request, shooting a beam of light into the air. The forward observer can then shoot an azimuth to the beams of light and perform a map resection. The beam of light must project straight up, and the observer must shoot an azimuth at the lowest visible point on the beam. With this system, pyrotechnics may also be shot into the air. The use of marking rounds as discussed for jungle operations also can help forward units self-locate.

Laser range finders must be used, especially when heat waves degrade distance estimating by conventional means. Observers can detect targets by observing dust clouds created by moving enemy forces. Employ smoke behind the enemy to silhouette them. The similarity of colors in the desert makes specific targets hard to spot. At night, illumination rounds burning on the ground behind the enemy have the same effect.

Usually, air observation is highly productive; however, the absence of landmarks in some areas degrades this capability. This problem is enhanced because aerial observers tend to see the battlefield in a two-dimensional perspective.

Lack of trees and hills makes aircraft more vulnerable to enemy air defenses. Use smoke to force enemy aircraft to fly higher, making acquisition easier. Radars are highly effective in the desert. Use them to aid in adjusting smoke onto targets.

Use smoke to—
- Complement ICM and FASCAM for obstructing and denying enemy use of roads.
- Silhouette the enemy, complement illumination fire at night, and increase the background contrast for sensors to acquire targets.

Priority targets for HC and WP smoke munitions and for generator smoke are likely enemy OPs, ATGM systems, and enemy air defense systems.

Winter Zones

The extreme weather conditions in arctic and subarctic regions are dramatic and severely impact on observation, mobility, and delivery of fire. Specific weather phenomena with which the smoke and fire support personnel must be concerned include whiteout, greyout, and ice fog.

Whiteout. The observer appears to be in a uniformly white glow. Neither shadows, horizon, nor clouds are discernible. The sense of depth and orientation is lost. Only very near, dark objects can be seen. Whiteouts occur over an unbroken snow cover and beneath a uniformly overcast sky. Blowing snow can cause the same effect.

Greyout. This is similar to whiteout except the horizon is distinguishable under greyout conditions. It occurs over a snow-covered surface during twilight conditions or when the snow is close to the horizon. There is an overall greyness to the surroundings. When the sky is overcast with dense clouds, there is an absence of shadows, resulting in a loss of depth perception.

Ice fog. This is common around inhabited areas during cold weather below 35 degrees Fahrenheit. Water vapor created by humans and vehicle exhausts may appear around soldier and equipment concentrations. Ice fog obscures vision and discloses locations by presenting a visible cloud to the enemy.

In winter zones, HC smoke and generator smoke are effective, and colored smoke may be used to silhouette the enemy. However, some of the canisters may be smothered in the deep snow. WP is effective; however, phosphorus may burn undetected in the snow for up to three to four days and may be a hazard to friendly troops subsequently moving through the area. HE/PD, HE/delay, ICM, and FASCAM are ineffective in deep snow. At least 40 percent of the blast from these munitions is smothered by the snow.

Weather and terrain conditions cause disorientation; changing terrain and poor maps make self-location difficult. Use marking rounds or searchlights and pyrotechnics from surveyed positions to help observers and smoke control officers orient themselves. Bright sunlight reflecting off snow-covered landscape causes snow blindness. Amber filters on binoculars and ob-

servation devices reduce the incidence of snow blindness.

Use of laser range finders is extremely critical because of lack of depth perception due to weather and terrain conditions. Use limited visibility positions to prevent degrading these systems. Use aerial observers because they can see deep and are not as prone to disorientation as are ground observers. Frequent poor weather reduces availability of CAS. Plan smoke use from CAS aircraft during windows of opportunity for good weather.

NBC Conditions

The physiological and psychological effects of NBC conditions impact on all elements of combat power. These conditions, documented in FM 3-100, create special problems when either the enemy or friendly force use smoke and obscurants. Encapsulation in full, individual protective equipment significantly reduces a soldier's ability to—

- **See.** Peripheral vision and visual acuity are restricted. Observers and smoke control officers are not able to accurately judge smoke on target or to estimate ranges for adjustments.
- **Hear.** Hearing is degraded. This is a significant problem on certain terrain, such as jungles, where fire and smoke are adjusted by Sound.
- **Communicate.** Communication is more difficult, as speakers and listeners often perceive that they cannot enunciate or hear as well. This has significant impact on adjusting fire or positioning smoke units.
- **React to stress.** Sustained operations are much more difficult, as encapsulation severely taxes human bodies. Leaders are at the greatest risk of combat ineffectiveness.

Deception

Employed smoke draws attention to the area it covers. This characteristic makes smoke use significant in supporting the deception story. However, never plan to use smoke by itself for deception.

Tactical deception draws the enemy's attention from the area of the main attack. The object is to make the enemy commit forces to the deception and not the main attack.

Smoke supports tactical deception operations by—

- Drawing attention to the deception activity.
- Limiting the enemy's ability to identify the deception for what it is: a ruse, feint, or demonstration.
- Protecting the force performing the deception.
- Making two-dimensional decoy material look real.

Planners must provide enough resources so that smoke support for the deception mission lasts as long as the deliberate mission. The key to a successful smoke deception is to make the enemy believe that the smoke support is for the main effort. However, smoke support for the deception force should not be so large that it divides or degrades the effectiveness of support for the main effort.

Plan to attack the deception target just as you would in any other operation. The standard battlefield applications of smoke—screening, obscuring, protecting, or marking-all apply. Use smoke to obscure, screen, protect, or mark a dummy or imaginary tactical smoke target area. Both the deliberate and deception mission should have the same visibility requirement and resources. Plan to use projected smoke extensively.

Planning considerations include–

- Ensure you place smoke on similar targets for both the main effort and deception. Deception and main effort smoke target areas should be Similar in size.
- Shift smoke assets to the main effort only when assaulting the objective and when immediate smoke is required to protect an element of the main effort.

Chapter 6

Sustainment Planning

Sustainment planning for smoke use in tactical operations must focus on the sustainment imperatives: anticipation, integration, continuity, responsiveness, and improvisation. There are several critical factors planners must consider to sustain smoke support in any given operation:

- Number and types of smoke delivery systems and the quantity of available resources.
- The commander's priorities for support.
- consumption factors of the delivery system and large-area smoke assets for the type of operation you are planning.
- Critical smoke delivery systems, whose continuous operation is crucial to the battle's success.
- Major tactical contingencies such as exploitation, pursuit, and withdrawal.
- Real estate management (for example, the location of delivery systems and combat service support [CSS] assets). This involves resolving conflicts in unit/base positions of several units in the same area or sector.

Commanders and their planners must plan to sustain all smoke delivery means that are in their tactical plan. Planners must consider the following:

- Plan for continuous support.
- Forward positioning of essential CSS, such as ammunition and petroleum, oil, and lubricants (POL). Execute this at night if possible. Artillery and mortar basic loads of smoke ammunition are limited. If your plan calls for sustained projected smoke, you may need to pre-position ammunition forward to sustain the operation. You may also want to pre-position smoke pots or WP main gun rounds.
- Use preplanned or preconfigured push packages (LOGPAC) of essential items. For missions where smoke requirements exceed existing assets, the commander should consider tailoring the LOGPAC to obtain the required items of ammunition or fuel.
- Plan for rapid resupply. If prepositioning is not possible, plan to rapidly resupply artillery and mortar units. Configure ammunition in the ammunition supply point (ASP) for rapid sling load or truck transport to user units. Coordinate with the division or corps support command for dedicated transportation assets for a specific period of time to support the operation.
- Upload as much materiel as possible on unit transportation assets. Use existing assets to carry specific mission needs, and down load items that can be brought forward later.
- Plan real estate management. Ensure the pre-positioned stocks and the terrain around these stocks are earmarked for the user unit. The division support command (DISCOM), corps support command (COSCOM), or area support group (ASG) is the focal point for resolving conflicts in unit/base positions.
- Plan direct delivery from supply to user. When you expect very high rates of ammunition or POL consumption, coordinate for direct delivery from the COSCOM CSS asset to the user unit. This requires intensive coordination to ensure transportation assets are in place at the critical time, as well as coordination for delivery locations.

Chemical companies, smoke generator companies, and platoons in particular do not have sufficient organic logistics assets to sustain combat operations. Because of this, chemical units heavily rely upon the supported unit for CSS. When organized under a chemical battalion or brigade, the parent headquarters acts as an intermediary between the chemical company and the division or corps support command for sustainment support.

Both the chemical unit and the supported unit conduct planning to sustain large-area smoke. Planning for smoke operations must ensure the smoke element has the following:

- Maintenance, supply, and recovery support (fixing and supplying).
- Transportation assets available (transporting).
- Tactical resupply of Class III (for example, fog oil, packaged POL, and MOGAS) (fueling).
- Sufficient personnel (manning).
- Fire support, to include tactical resupply of Class V, and security (arming and protecting).

Maintenance, Supplies, and Logistics

Smoke generators are very limited in number on the battlefield. Smoke generators are also resource-intensive items of equipment. Chemical brigades and battalions do not have a support platoon to manage, pick up, and deliver supplies. Chemical units, and smoke units in particular, are very dependent upon the supporting CSS structure to configure and deliver "push" packages of supplies. Appendix E outlines smoke sustainment planning guidance.

It is essential that commanders and planners consider logistical support for smoke units in the overall tactical plan for an operation. The plan must specify–

- Support relationship between the supported unit and the smoke unit.
- Which activities (TAACOM, COSCOM, ASG, support group, DSA, BSA, or field trains) provide what type(s) of support for the smoke unit:
  - Class I, II, IV, VI, and VII.
  - Class III package (fog oil and other packaged POL).
  - Class III bulk (MOGAS, diesel).
  - Class V (small arms, mines, grenades, and explosives).
  - Class VIII and general medical support.
  - Class IX intermediate level maintenance support, less smoke generator specific parts.
- Consumption rates for the specified mission such as amount of fog oil and other POL needed to sustain smoke operations.
- "Push" packages to support committed units (for example, delivery times and locations, quantities, and frequency).
- Transportation support:
  - Availability of transportation assets.
  - Preplanned deliveries to provide the "push" package.
- Priorities for support of units or areas.

Supporting Units

The smoke unit commander specifies the items for inclusion into a "push" package. The CSS unit specified in the plan will configure supplies for rapid distribution to the smoke unit. Normally, support to smoke units is on an area basis. When providing this support, support units use varying combinations of unit distribution such as long-range patrol (LRP) and supply point distribution procedures.

Unit distribution is the preferred method for resupplying smoke units. The supporting unit delivers supplies to the smoke unit's area using preplanned or dedicated transportation assets. The supporting unit generally arranges this transportation, although the transportation assets may be dedicated to resupplying the smoke unit for a particular mission only. The supporting unit should plan for throughput whenever possible.

An alternate means of resupply is supply point distribution. The supporting unit issues supplies from a supply point to the smoke unit. The smoke unit uses its own limited transportation assets to move the supplies to its area of operations.

When determining the type of distribution to be used to support smoke units, logistics planners at all levels should consider–

- Availability of personnel and equipment to deliver and pick up supplies.
- Missions of the supported forces.
- Adequacy of road networks in the area of operations.
- Priorities for use of the roads.
- Anticipated distances between supporting and supported forces.
- Locations of the supported forces.
- Threat to road and rail networks.

Basic Load

Basic load is the amount of equipment and supplies required by a unit to sustain itself until resupply can be effected. The basic load is approved by the commander. The basic load is not a fixed quantity; it may be altered as situations dictate. For example, a smoke unit conducting a prolonged smoke operation may have its basic load of smoke pots increased for that particular operation.

One method of easing the resupply requirements of smoke units is tailoring of the basic loads. Extended smoke operations away from the main force can be given larger or different basic loads of fuel, parts, or other necessary supplies. Use the consumption tables in Appendix E as a guide for preparing unit basic loads.

Fog Oil Resupply

Fog oil is a packaged POL product arriving in 55-gallon drums. Support units can bulk fog oil by transferring the fog oil from the 55-gallon drums to fuel pods or tank and pump units. The fog oil used in smoke operations comes through the corps and division support areas. It may be delivered as far forward as the brigade support area by the supporting CSS unit. From here the smoke unit's fuel supply elements pick up the fog oil. Based on the type and duration of the smoke mission, the fuel supply element either establishes a forward fuel supply point or keeps stocks uploaded on organic vehicles. For rear area missions the smoke-fuel supply point may be supported from existing Class III or other supply activities.

There are two methods for fog oil resupply on-line resupply and off-line resupply.

On-line resupply. Stationary smoke points are resupplied on line during a smoke mission. This requires the fog oil and MOGAS resupply squad to move to each point as needed. The resupply squad or section will move tank and pump units (TPUs) to the line,

drop the drums of fog oil at the smoke point, or pre-position drums at a follow-on smoke point. This increases the vulnerability of the resupply squad or section and the smoke point.

Off-line resupply. Mobile units are resupplied by rotating individual systems through a fuel resupply point 1 to 2 kilometers to the rear of the smoke line. You can also resupply stationary units that are displacing in this manner.

Fire Support and Security

When planning for the use of smoke in support of combat operations, it is essential commanders and operational planners recognize the vulnerability of smoke units. Smoke generator units conducting smoke operations leave a very recognizable signature on the battlefield. Smoke by its very essence attracts attention. An observer only needs to follow the smoke streamer to its source to target the individual smoke-producing device. Smoke generator operators and smoke unit commanders are acutely aware of this and utilize every measure available to reduce this signature.

Some of these steps include –

- Making maximum use of natural cover and concealment.
- Using reverse slope positioning.
- Using self-protecting smoke (for example, smoke pots upwind of generator positions).
- Continuously moving mobile systems within designated areas to minimize effective targeting.
- Staggering positions of generators.
- Digging in or hardening.
- Making smoke from flanks and stand-off positions whenever possible.

While the above actions will enhance the smoke unit's survivability, proper employment by the supported unit is essential. As an example, mechanized smoke systems provide some small-arms protection for the crew and are less vulnerable to indirect fire than wheeled smoke systems.

Lessons learned at the NTC consistently demonstrate that mechanized smoke systems suffer high-loss rates when they are among the lead elements of armored assaults. While improper employment at the NTC serves as a valuable training aid for commanders, the same mistake in combat will result in the loss of a significant and scarce combat multiplier.

Reconstitution of battlefield losses will be slow. They may not occur at all based on the availability and priority of distribution for such a limited asset. In a rapidly moving armor assault, the commander may wish to plan for additional smoke support from his indirect fire artillery using WP or HC smoke projectiles integrated into preparatory fire. This fire placed on or in front of the objective may accomplish the desired result and not expose mechanized systems to unnecessary risk.

Fire Support

Supporting smoke assets coordinate with the supported unit for fire support.

Fire support is based on artillery availability and the coordination that takes place among the smoke unit, chemical staff office, S3/G3, and FSO. Integrate the smoke unit fire plan with the supported unit fire plan. Fire support planning must consider—

- Priorities of fire support.
- Availability of smoke rounds (mortar and artillery).
- Named areas of interest (NAI) and target areas of interest (TAI) of the maneuver unit.
- Coordination with fire support assets for the primary, alternate, and supplemental smoke operations areas or points.
- On-call targets (nominated by the smoke unit).

Security

Plan for the security for smoke units based upon availability of the supported unit's assets and priorities. When security forces are provided for smoke assets, coordination measures include –

- Determining needed duration of security support.
- Determining size of security element.
- Locating overwatch positions for security elements.
- Determining smoke and security element leaders understand the commander's concept, fire support plan, and communication procedures, and are aware of smoke tactical resupply locations.

Personnel Sustainment

Smoke support occurs in many types of terrain under different weather conditions. Operations may occur in NBC-contaminated areas. Leaders balance mission requirements against protection requirements. They consider visibility constraints and heavy work rates during smoke missions. Specifically, it is difficult to see in smoke. It is more difficult to see in smoke when in full individual protective equipment (IPE). Heat buildup becomes critical to the welfare of the soldier. This is especially true when the operator of the M157 smoke generator set is "buttoned-up" inside the M1059 mechanized smoke gener-

ator in full IPE in support of a mechanized or armored division.

Smoke generator crews may be difficult to replace in future conflicts. Therefore, you must focus on maintaining the available force at peak combat effectiveness. Leadership is the key to maintaining the strength and spirit of the fighting force. Leaders must assemble, transport, and distribute their units as the commander requires in his task organization, yet conserve their fighting strength. Leaders must give special consideration to—

- Health services.
- Administrative support.
- Morale and welfare activities.
- Discipline.
- Stress management.
- Replacement planning.

Limited visibility has a significant impact on sustainment operations. It increases the time and decreases sustainment responsiveness. Support and smoke units should thoroughly rehearse sustainment activities prior to execution of the plan.

Chapter 7

VISUAL-INFRARED OBSCURANTS

Today virtually every nation and non-state organization has access to—

- advanced tactical sensors for target acquisition (thermal imagers) and intelligence gathering surveillance systems (ground and air reconnaissance).
- precision-guided munitions delivered by artillery, missiles, and aircraft that operate in the IR region of the electromagnetic spectrum.

These capabilities are available through internal manufacturing or purchase on the world market.

These thermal imaging sights allow them to acquire and engage targets through visual smoke, at night, and under adverse weather conditions. To counter the increasingly sophisticated sensor threat, the M56 and M58 smoke generator systems provide maneuver commanders the capability to control and dominate the visual through far infrared (IR) portions of the electromagnetic spectrum using visual (fog oil) and infrared (graphite) obscurants.

VISUAL-INFRARED OBSCURANT GENERATOR SYSTEMS

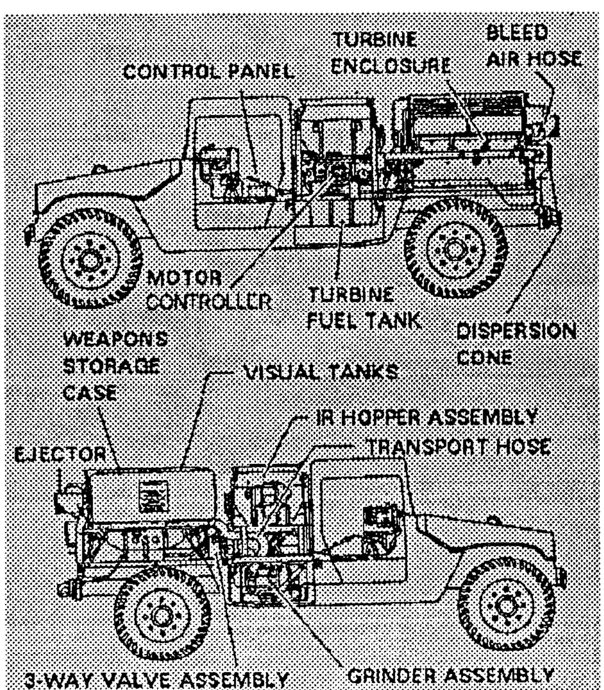


Figure 7-1. M56 Smoke Generator System.

The M56 Smoke Generator System (Figure 7-1) mounted on an Ml113 HMMWV is organic to motorized smoke units and dual-purpose smoke/decontamination units. The M56 can produce 90 minutes of visual/near infrared obscurant and 30 minutes of infrared obscurant without resupply. This system can produce obscurants while mobile or stationary.

The M58 Smoke Generator System (Figure 7-2) mounted on the M113A3 APC is organic to mechanized smoke units. The M58 can operate mobile or stationary. It can produce 90 minutes of visual/near infrared obscurant and 30 minutes of

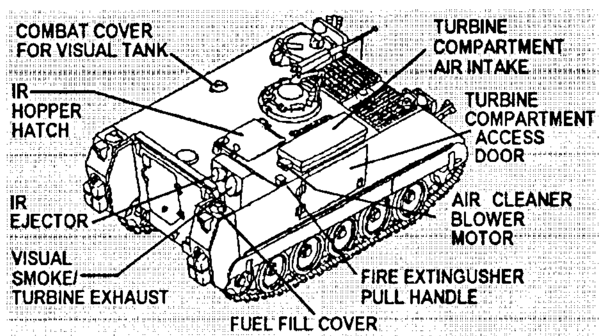


Figure 7-2. M58 Smoke Generator System.

infrared obscurant without resupply. Chassis improvements allow the M58 to keep pace with mechanized and armor units. The systems are equipped with a driver's thermal imager and an NBC contamination particulate filter unit.

Each system can selectively produce visual obscurants (vaporized fog oil) to defeat acquisition in the visual, and near infrared and infrared obscuration (graphite flakes) to defeat target acquisition devices that operate in the mid and far infrared. The two obscurants may be employed simultaneously or separately. If employed simultaneous y, the threat force's capability to acquire targets with day sights and thermal imagers will be degraded. If employed separately, the visual obscurant will degrade day sights and the IR obscurant will degrade the thermal imagers.

OBSCURANT EFFECTS ON SENSORS/SEEKERS

Visual and infrared obscurants have distinctly different effects on friendly and threat force sensors.

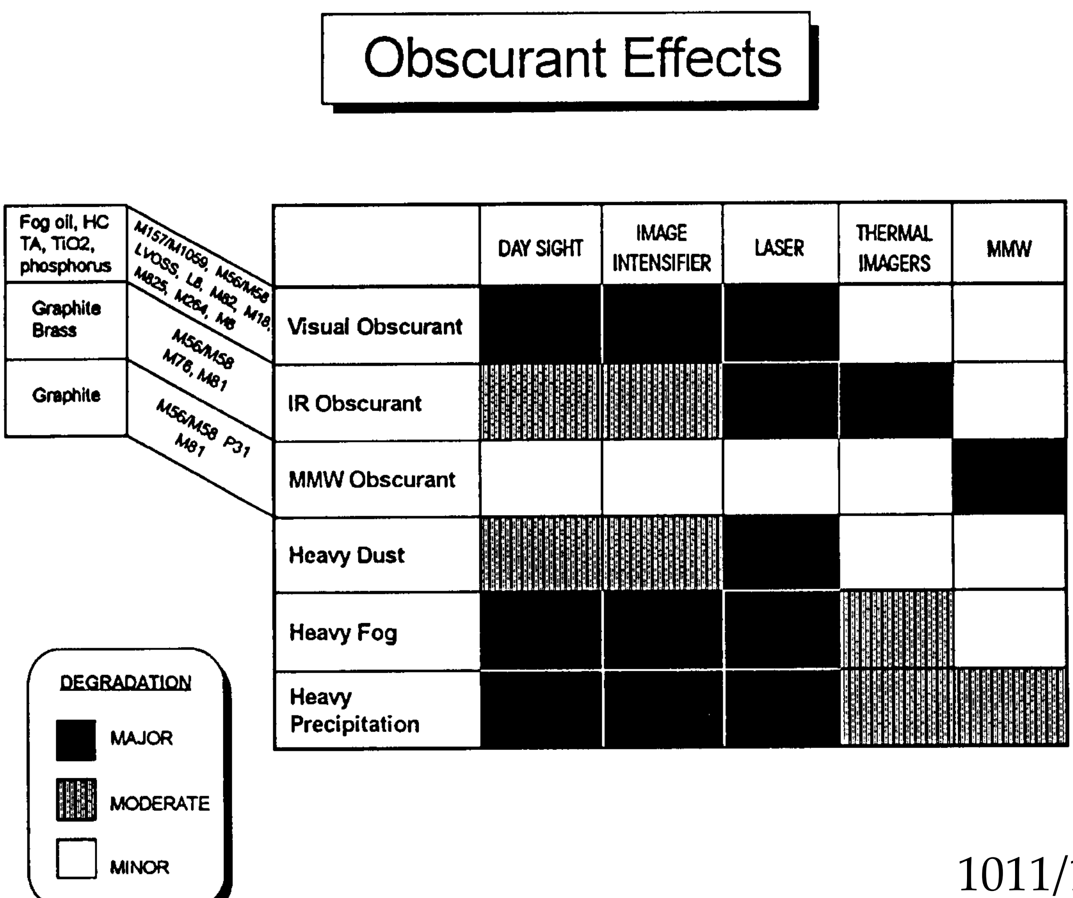
Therefore, commanders and staffs must understand the opportunities and limitations associated with each. Employment of infrared obscurants is a double-edged sword. A maneuver commander may want the added concealment offered by an infrared obscurant (graphite), but must accept the fact it will also degrade his own systems. Commanders and staffs must identify the threat sensor/seeker systems to be countered, determine the obscurant to be employed, and identify impacts on their own systems. Table 7-1 depicts the types of sensors and seekers found on today's battlefields and the relative degree of degradation caused by various natural end man-made obscurants.

VISUAL-INFRARED OBSCURANT CONCEPTS

Intelligence preparation of the battlefield (IPB) determines how the threat arrays sensors and seekers on the battlefield. After the IPB process has been accomplished, the chemical battle staff develops a plan to integrate smoke and obscurant assets into the operational plan. The goal of the obscurant plan is to defeat critical threat sensors and seekers. For example, the IPB process has determined that the threat possesses a significant thermal imagery capability located with his reconnaissance assets. The smoke plan would likely focus on employing IR obscurants whenever and wherever the threat might attempt to utilize his reconnaissance assets.

The doctrine for IR obscurants is different from the doctrine for visual obscurants. IR obscurants provide the capability to defeat a significant threat asset—thermal imagers. Visual obscurants are used primarily to provide force protection from a threat having limited electro-optical capabilities such as first generation FLIR or with an even lesser capability such as systems that can only operate in the visual region of the electromagnetic spectrum. Overall, IR obscurants will be employed directly on the threat or between the threat and friendly forces. Visual obscurants are employed on friendly forces to provide

Table 7-1. Sensors and Seekers.



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protection while still allowing for the ability to maneuver within the obscurant cloud.

Offense

Employment of an infrared obscurant in offensive operations gives the maneuver commander an additional element of combat power. IR obscurants are able to defeat threat sensors and seekers. Two missions should be considered. One is to utilize the IR obscurant as a screen to prevent thermal ground sensors from detecting and identifying friendly forces. Another is to utilize the IR obscurant to obscure threat sensors. In this mission, given favorable weather conditions, the smoke plainer would employ the IR obscurant directly on the threat sensors.

Defense

IR obscurants in the defense will provide protection from smart weapons and prevent those weapons from acquiring their targets. Although the employment of IR obscurants reduces the friendly ability to maneuver, the commander may choose this option to increase the survivability of his forces in the event that other resources are unavailable to defeat the threat's smart weapons. For example, IR obscurant would provide considerable protection from smart weapons for rear area operations such as port facilities, logistical sites, and airfields.

Cloud Dynamics

Infrared obscurants are subject to the same weather and terrain considerations as visual obscurants. For planning purposes, the IR obscurant cloud will travel approximately the same distances as a visual cloud and will cover the same size target area. Visibility criteria in terms of *haze*, *blanket*, and *curtain* are not true for IR obscurants. Infrared clouds are defined in terms of transmittance value in relationship to percentage of probability of detection. Given wind speed, source strength, and downwind distance (Annex H), chemical staffs are able to estimate probability of friendly forces being detected when screened or protected by infrared obscurants.

Smoke Control

Generally, smoke control is the function of the smoke platoon leader or the smoke company commander under the direction of the maneuver commander, a breach or river crossing site commander, or a facility commander. Smoke control procedures will be essentially the same for visual and infrared screens. However, at *night*, actual observation of the infrared cloud requires a thermal viewer. Without an IR sensor, smoke control officers will rely on the fog oil cloud to adjust target coverage or on information provided by the supported maneuver unit.

Coordination Measures

Infrared obscurants offer additional options to the commander: visual only, IR only, or visual/IR obscurants. The chemical battle staff must assist the commander in recommending the appropriate type obscurant based on IPB. Limiting factors may be based on planned friendly activity, the need to prevent signaling a friendly presence to the threat force, or danger inherent to friendly operations that might result in increased fratricide.

Smoke Control Graphics

Smoke target numbering systems and graphic control techniques will be increasingly important as commanders and staffs come to rely more heavily upon digitization. Battle staffs will maintain electronic overlays of planned smoke missions (similar to trafficability overlays) to allow for coordination of mission planning with adjacent and higher organizations. With the fielding of large-area infrared smokes, graphic control aids must be developed to portray *no smoke* areas, *visual only* smoke targets, *visual-infrared* smoke targets, and *infrared only* targets. Target numbering procedures should be standardized to enable adjacent units to recognize immediately smoke missions that may adversely affect their operations due to wind shifts, the cloud traveling farther than anticipated, or flank units perhaps being silhouetted. Although subject to local SOPs, visual only smoke target numbers should begin with a V followed by five digits. IR only smoke target numbers should begin with IR followed by four digits. Visual-infrared target numbers should begin with VIR followed by three digits.

Troop Safety

The same masking requirements and procedures for fog oil employment apply for infrared (graphite) obscurants. Overall, carry the mask when participating in operations that include the use of infrared obscurants. Mask when passing through or operating in a dense cloud. If duration of exposure will exceed 4 hours or breathing difficulties occur, masking is required.

LOGISTICAL SUPPORT

Logistical support for chemical smoke units requires special consideration with the addition of infrared smoke material (graphite). One 5-ton truck is capable of carrying the weight (and volume) of 9 barrels of fog oil and up to 4,350 pounds of IR obscurant simultaneously. If two 5-ton trucks are used to resupply 6 generators, the travel time to a supply point, reloading with fog oil and IR obscurants, and returning to the mission site must not exceed 75 minutes. When consecutive infrared missions are desired to support maneuver operations, the chemical staff with the G4/S4 anticipates resupply requirements and ensures that the smoke plan is supportable. Use the consumption table (Table 7-2) as a logistical planning tool for visual infrared smoke operations. Planners should keep in mind the M56 and M58 smoke generator systems have a variable setting capability for both IR (graphite) and fog oil modules. This allows the operator to control the rate graphite and fog oil is consumed. For example, at a consumption rate of 5 pounds per minute, the system can produce 1 hour of IR obscurant. If the consumption rate is 10 pounds per minute, the system can produce 30 minutes of IR obscurant.

CONCLUSION

The M56/M58 smoke generator systems provide commanders and staffs an additional element of combat power. IR obscurants in any operation can be employed to *protect* the force, *screen* friendly maneuvers, or to *obscure* and attack threat sensors and seekers. IPB is critical in planning infrared missions by identifying threat sensors and seekers and how they are arrayed in theater. The chemical battle staff, by participating in the IPB process, war gaming, and rehearsals will facilitate an effective obscurant plan to support the commander's intent. The IPB process, focusing on how the threat arrays his sensors and seekers on the battlefield, are critical steps in planning the employment of IR obscurants.

Table 7-2. Consumption Table.

CONSUMPTION TABLE
M56 / M58 SMOKE GENERATOR SYSTEM

COMPONENT	1 HR	2 HR	6 HR	24 HR	48 HR
GAS TURBINE ENGINE (12 gal/hr)	12	24	72	288	576
VISUAL SMOKE MODULE (1.33 gal/min)*	80	160	479	1915	3830
IR MODULE**	600	1200	3600	14,400	28,800

* FOG OIL CONSUMPTION IS BASED ON MAXIMUM VARIABLE SETTING.

** IR OBSCURANT MODULE IS FED AT A VARIABLE RATE FROM 5 TO 10 lbs/min. CONSUMPTION IS BASED ON MAX SETTING.

M56 CAPACITIES: FOG OIL TANK 120 gal, IR MODULE 300 lbs, GAS TURBINE ENG 26 gal.

M58 CAPACITIES: FOG OIL TANK 120 gal, IR MODULE 300 lbs, GAS TURBINE ENG 95 gal.

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Appendix A

Smoke Planning

Chapter 1 describes the general considerations for planning smoke support. This appendix provides procedures for preparing smoke planning documents and gives some examples. The smoke planning document examples include a smoke estimate format (Figure **11),** smoke target list work sheet (Figure 12), and a smoke annex format (Figure 13). In addition, Figure 14 shows a coordination checklist for chemical unit commanders to use when they receive orders for a smoke mission.

Chemical staff officers must coordinate all smoke support with the G3/S3, FSCOORD, and lateral units. These planning document examples contain several mechanisms to help staff officers verify such coordination.

Target Analysis Procedures

Coordinate with the commander or G3/S3 to determine obscurant requirements for the unit. Coordinate with the FSO, and nominate targets for obscuration. Identify targets within the FSO's capability. Also identify targets not within the FSO's capability.

Record targets on the target list work sheet.

Identify smoke delivery means to support the operation:

- Smoke generator unit(s).
- Mortars.
- Maneuver combat vehicles.
- Field artillery unit(s).
- Close air support assets.
- Naval gunfire.
- Other delivery means.

Plan targets, to include the following considerations:

- Which delivery means to use. For guidance, see the employment matrixes.
- Which obscurant to use. For guidance, see Appendix B, Figure **16,** page 73.
- Duration of smoke on each target.
- Time to fire or make smoke.

Coordinate with the G3/S3 for the final target list and schedule of smoke engagement with other than fire support assets.

Coordinate with the FSO for the final target list and schedule of fire. Designate the person, event, or time that will initiate the smoke mission. Coordinate with adjacent units, and check weather conditions.

Add or delete smoke missions on the basis of available assets and weather and terrain factors. Coordinate with any adjacent units not previously affected, but which may now be affected by smoke.

Prepare the smoke support annex to the OPLAN/OPORD.

Planning Documents

Smoke Estimate Format

After receiving the restated mission and planning guidance from the commander, the chemical officer prepares a smoke estimate (Figure 11).

Smoke Target List Work Sheet

Mandatory entries in a smoke target list work sheet include —

- **Smoke target number.** Assign a control number to identfy the smoke target. The smoke control number contains five characters. The first character is a letter; the following four are numbers. A local SOP will establish how to assign these numbers. They are not the target number for fire support purposes. Fire support target numbers may be recorded in the remarks column. Smoke target numbers are five characters in length. The first character is a letter; the final four are numbers. Divisions and higher field headquarters may assign a specific group of numbers to organizations (for example, 1st Bde is A1001 through A1999; 2d Bde is B2001 through B2999). These numbers provide the chemical staff officer with a brevity code for smoke

- **Target description.** Write a brief description of the target (for example, combat reconnaissance patrol).
- **Target location.** Enter the center of mass UTM grid coordinates for the target.
- **Size.** Give the dimensions of the target in meters.
- **EO system.** This is the system you will attack with smoke/obscurants.
- **Delivery means.** Identify potential delivery means for the smoke.
- **Type of smoke.** Identify the type of smoke/obscurant to employ.
- **Priority.** This is the priority of attack based on fire support's target value analysis.
- **Remarks.** Self-explanatory.

Smoke Annex to OPLAN or OPORD

The smoke annex to a plan or order implements the commander's decisions concerning how to use smoke in the **operation.** The chemical staff officer prepares and coordinates the smoke annex. He or she, as a minimum, provides copies to subordinate and adjacent units (if affected by the smoke), the G3/S3 and G4/S4 officers, FSCOORD, and smoke unit leaders.

Smoke Mission Coordination Checklist

Smoke unit commanders or leaders use this checklist to verify coordination with the supported unit and any adjacent units that might be affected by the smoke. The chemical staff officer provides most of the information (such as visibility criteria and target location); but, the smoke unit leader must personally finalize coordination, whenever, possible.

Employment Matrixes

Use the seven employment matrixes (Tables **4 through 10,** pages 65 through 71) to determine the appropriate delivery means for specific smoke targets. The tables cover general, hasty attack, deliberate attack, defense, retrograde, special operations, and MOUT situations.

CLASSIFICATION

Copy ___ of ___ Copies
Issuing Headquarters: ___________________
Date–Time Group: _____________
Message Reference Number: __________

SMOKE ESTIMATE

References: Map, charts, smoke overlays, and relevant documents.

Time zone used throughout the order: __________

1. Mission. This is the mission statement from the commander's estimate.

2. The Situation and Courses of Action.

a. Considerations Affecting the Possible Courses of Action.

(1) Operations to be supported.

(2) Characteristics of the area of operations.

(a) Weather.

(b) Terrain.

(c) Other pertinent factors.

b. Enemy Situation. Include potential weaknesses we wish to exploit and nominate potential targets.

c. Own Situation. Include smoke production asset status.

(1) Tactical situation.

(2) Smoke assets (projected, generator, self-defense) availability.

(3) Personnel, logistics, and CMO.

(a) Smoke munitions.

(b) Fog oil.

(c) MOGAS.

(d) Smoke generator unit readiness.

(e) Available transportation support.

CLASSIFICATION

Figure 11. Sample format for a smoke estimate. (Part 1 of 2)

CLASSIFICATION

d. Anticipated Difficulties or Difficulty Patterns.

e. Own Courses of Action.

3. Analysis of Courses of Action. Analyze each in light of critical incidents, times, areas, and significant difficulties.

4. Comparison of Courses of Action. Evaluate deficiencies from a smoke delivery and target defeat perspective. List advantages and disadvantages including methods to overcome deficiencies.

5. Conclusions. Indicate if mission is supportable and which course of action best supports the mission.

(Chemical Officer)

Annexes (as required)

Distribution: Must include G2/S2, G3/S3, and FSO at a minimum.

CLASSIFICATION

Figure 11 continued. (Part 2 of 2)

Smoke Target List Worksheet

Smoke Target No.	Target Description	Target Location (UTM Grid)	Size (in Meters)		EO System	Delivery Means	Type of Smoke	Priority	Remarks
			L x W						

SAMPLE

Figure 12. Target list worksheet example.

CLASSIFICATION

Copy ___ of ___ Copies
Issuing Headquarters: ______________
Date–Time Group: _________
Message Reference Number: ___________

Annex __ (Smoke Support) to OPLAN (or OPORD)

REFERENCES: (Map, charts, smoke overlays, and relevant documents.)

Time zone used throughout the order (or plan): _________

1. SITUATION.

a. Enemy Forces. See Annex ___ (Intelligence) to OPLAN/OPORD No.______. (Add any items identified in the smoke estimate but not included in the intelligence annex. Ensure you cover weather and terrain factors.)

b. Friendly Forces. (Include information concerning smoke assets, not covered by the operation order, that are available in higher, adjacent, supporting, and reinforcing units.)

c. Attachments and Detachments. (List assets supporting the smoke mission, attached to or detached from the issuing headquarters.)

d. Assumptions. (OPLAN only)

2. MISSION. (State the mission for smoke delivery means.)

3. EXECUTION.

a. Concept of Operation. (Describe the concept for employment of smoke assets, to include the commander's intent and support priorities. Cover the role of smoke in support of the deception plan.)

b. (In subsequent lettered subparagraphs, give the specific tasks to be accomplished by smoke assets.)

(1) Generator smoke. (List specific missions, targets, and tasks for smoke generator organizations.)

(2) Projected smoke. See Annex __ (Fire Support).

(3) Other smokes. (List specific missions for units to use VEESS, smoke pots, or other smoke production means.)

CLASSIFICATION

Figure 13. Sample smoke annex to an OPLAN or OPORD. (Part 1 of 3)

CLASSIFICATION

c. Coordinating Instructions. (State coordination or control applicable to two or more elements of the command.)

(1) (Designation of smoke control officer.)

(2) (Key person, time, or location to initiate smoke.)

(3) (Smoke target list and overlay.)

(4) (Schedule of smoke delivery.)

4. SERVICE SUPPORT

a. Material and Services. (Include information pertaining to availability; procedure for distribution; prestock points; and transportation of smoke munitions, bulk or packaged smoke generator fuels, and other supplies, to include—

- Which activities (TAACOM, COSCOM, ASG, support group, DSA, BSA, or field trains) provide what type(s) of support for the smoke unit:

  —Class I, II, IV, VI and VII?

  —Class III package (fog oil and other packaged POL)?

  —Class III bulk (MOGAS, diesel)?

  —Class V (small arms, mines, grenades, and explosives)?

  —Class VIII and general medical support?

  —Class IX intermediate level maintenance support, less smoke generator specific parts?

- Consumption rates for the specified mission (for example, amount of fog oil and other POL needed to sustain smoke operations).

- Push packages to support committed units (for example, delivery times and locations, quantities, and frequency).

- Transportation support:

  —Availability of transportation assets.

  —Preplanned deliveries to provide the push package.

- Priorities for support of units or areas.)

b. Miscellaneous.

CLASSIFICATION

Figure 13 continued. (Part 2 of 3)

CLASSIFICATION

5. COMMAND AND SIGNAL.

a. Command. (State procedures for control of smoke assets and location of primary and alternate command posts.)

b. Signal. (CEOI reference.)

(Commander)

(Authentication)

ENCLOSURE (If operation overlay is enclosed, describe enclosure.)

DISTRIBUTION:

CLASSIFICATION

Figure 13 continued. (Part 3 of 3)

CLASSIFICATION

1. Grid coordinates of the smoke mission (target location): ____________________

2. Start and stop date/time/event of smoke mission:

   START Date/Time/Event: ____________________

   STOP Date/Time/Event: ____________________

3. On/off-station date/time for the smoke unit(s):

   ON-STATION date/time: ____________________

   OFF-STATION date/time: ____________________

4. Type of visibility in the smoke required: ____________

   (Blanket: less than 50 meters.) (Haze: 50 to 150 meters.)

5. Enemy location(s)/activity: ____________________

6. Communications:

   (a) Supported unit's frequencies and callsign:

   Primary Frequency: ____________ Alternate: ____________

   Callsign: ____________

   (b) Supporting unit's frequencies and callsigns:

   Primary Frequency: ____________ Alternate: ____________

   Callsign: ____________

7. Supporting unit's command relationship to the supported unit (DS, GS, attached, OPCON):

____

CLASSIFICATION

Figure 14. Sample smoke mission coordination checklist. (Part 1 of 2)

CLASSIFICATION

8. Supported units' responsibilities to the supporting unit (for example, maintenance, transportation, fuel, and feeding): ______________________

9. Required staff coordination for the mission: (Check applicable staff sections.):

S2 ___ S3 ___ S4 ___ FSE ___ ALO ___ ENG ___

10. Location of supported unit's TOC: ______________________

11. Challenge, password(s), and code word(s): ______________________

12. Coordination effected with subordinate units, DATE/TIME: ______________________

13. Coordination effected with adjacent units, DATE/TIME: ______________________

14. Designate supply route(s) in/out of area: ______________________

15. Determine local weather conditions and peculiarities: ______________________

16. Determine any additional security requirement (for example, supporting unit requirement(s) for security forces): ______________________

17. Liaison information (between supported unit and supporting unit): ______________________

18. Smoke operation overlay: ______________________

19. After action report (AAR) to division NBCC: ______________________

Date/Time Mission Started: ______________________

Duration of Mission: ______________________

Fog Oil/ MOGAS Consumption: ______________________

Mission Issues/Problems: ______________________

Mission Results (success or failure): ______________________

CLASSIFICATION

Figure 14 continued. (Part 2 of 2)

Table 4. Smoke target matrix for general use.

Target \ Weapon	Artillery Smoke	Mortar Smoke	Smoke Pots	Smoke Generators	Smoke Hand Grenades	Smoke Rockets	Grenade Launchers	VEESS
Obscure Objective	X	X			A	X	X	
Conceal Breaching	A	A	X	X				
Conceal Movement	A	A	A	X	A		A	A
Blind Snipers	A	A			A	X	X	
Hide Vehicle From ATGM	A	A			X		X	X
Screen Bridging Operations	A	A	X	X	A	A	A	A
Segregate Enemy	X	X				A	A	
Support Deception	A	A	A	X				A
Screen Facilities			X	X				
Counter-smoke	X	X	A			X	A	

X = Primary System
A = Alternate or Secondary System

Table 5. Smoke target matrix for hasty attack.

Target \ Weapon	Artillery Smoke	Mortar Smoke	Smoke Pots	Smoke Generators	Smoke Hand Grenades	Smoke Rockets	Grenade Launchers	VEESS
Obscure Objective	X	X		A		A	A	
Conceal Breaching	A	A	X	X		A		A
Conceal Movement	A	A	X	X	A		A	A
Blind Recon	X	X			A	X	A	
Hide Vehicle From ATGM							X	X
Screen Bridging Operations	A	A	X	X	A	A	A	A
Segregate Enemy	X	X			A	A	A	
Support Deception	A	A	X	X				A
Silhouette Enemy		X	A	A	A		A	
Isolate Enemy Aviation	X	A	A	A				

X = Primary System
A = Alternate or Secondary System

Table 6. Smoke target matrix for deliberate attack.

Weapon / Target	Artillery Smoke	Mortar Smoke	Smoke Pots	Smoke Generators	Smoke Hand Grenades	Smoke Rockets	Grenade Launchers	VEESS
Obscure Objective	X	X						
Conceal Breaching	A	A	X	X		A		A
Conceal Movement	A	A	X	X	A		A	A
Blind Recon	X	X			A	X	A	
Hide Vehicle From ATGM				A			X	X
Screen Bridging Operations	A	A	X	X	A	A	A	A
Segregate Enemy	X	X					A	
Support Deception	A	A	X	X				A
Silhouette Enemy		X	A	A	A		A	
Conceal Assembly Area			X	X			A	

X = Primary System
A = Alternate or Secondary System

Table 7. Smoke target matrix for defense.

Target \ Weapon	Artillery Smoke	Mortar Smoke	Smoke Pots	Smoke Generators	Smoke Hand Grenades	Smoke Rockets	Grenade Launchers	VEESS
Silhouette Enemy	X	X	A			X		
Conceal Obstacles/ Emplacement			X	X				A
Conceal Movement	A	A	X	X	A	A	A	A
Blind Recon	X	X			A	X	A	
Hide Vehicle From ATGM			A	A	A		X	X
Isolate Enemy Aviation	X	A	A	A				
Segregate Enemy	X	X				A		A
Support Deception		A	A	X				A
Screen Facilities			A	X				
Counter-smoke	X	X				A		

X = Primary System
A = Alternate or Secondary System

Table 8. Smoke target matrix for retrograde.

Target \ Weapon	Artillery Smoke	Mortar Smoke	Smoke Pots	Smoke Generators	Smoke Hand Grenades	Smoke Rockets	Grenade Launchers	VEESS
Obscure Positions	A	A	X	A		A		
Conceal Mobility Operations			X	X				A
Conceal Movement			A	X	A		A	X
Blind Recon	X	X			A	X	A	
Hide Vehicle From ATGM			A	A	A		X	X
Isolate Enemy Aviation	X	X	A	A				
Segregate Enemy	X	X	A		A	X	A	
Support Deception		A	X	X				A
Screen Facilities			A	X				A
Counter-smoke	X	A				X		
Isolate Pursuing Forces	A	A				X		
Silhouette Enemy	X	X	A			X		

X = Primary System
A = Alternate or Secondary System

Table 9. Smoke target matrix for special operations.

Target \ Weapon	Artillery Smoke	Mortar Smoke	Smoke Pots	Smoke Generators	Smoke Hand Grenades	Smoke Rockets	Grenade Launchers
Obscure Objective	X	X		A	A	X	X
Conceal Breaching		X	A		A		
Conceal Movement				X	A	A	A
Blind Snipers	A	A			A	A	X
Conceal Infiltration			A		A	X	A
Screen Exfiltration			A		X		
Segregate Enemy	X	X				X	A
Support Deception	A	A	A	X	A	A	A
Screen Facilities			A	X			
Counter-smoke	A	A				X	

X = Primary System
A = Alternate or Secondary System

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Table 10. Smoke target matrix for MOUT.

Target \ Weapon	Artillery Smoke	Mortar Smoke	Smoke Pots	Smoke Generators	Smoke Hand Grenades	Smoke Rockets	Grenade Launchers	VEESS
Obscure Objective	X	X		A	A	X	X	
Screen Breach Operations			X	X				A
Conceal Movement	A	A		X	A		A	X
Blind Snipers					A	X	X	
Hide Vehicle From ATGM	A	A			A		A	X
Screen Bridging Operations	A		A	X				
Segregate Enemy	X	A				A	A	
Support Deception	A	A	A	X				A
Screen Facilities				X				
Counter-smoke	X	A				X	A	

X = Primary System
A = Alternate or Secondary System

Appendix B

Electro-Optical Systems

Smoke and obscurants influence the visual portion of the electromagnetic spectrum. They also provide protection for our forces by influencing frequency ranges we do not normally perceive with our senses.

All sensory equipment (to include the human eye, viewers, vision enhancement devices, trackers, and seekers) requires a certain amount of energy (a minimum threshold) before they can perform their functions. A sensor will also fail to function if the level of energy, in the frequency range the device is designed to work within, is too great (a maximum threshold). Smoke and obscurants provide us a means to render sensors ineffective, by decreasing or increasing the amount of energy available to the device or sensor (Figure 15).

There are three categories of obscurants: natural, by-product, and artificial. We can use natural obscurants advantageously if we correctly forecast the weather. Darkness, fog, sandstorms, and precipitation are examples of natural obscurants. By-product obscurants on the battlefield result from combat actions. Examples include the smoke caused by the burning of buildings and equipment, dust raised by maneuvering units, and the airborne dust and particles thrown by exploding artillery and mortar fire.

We produce artificial obscurants with smoke production equipment or munitions as described in Chapter 1 and Appendixes D and E. We use these specifically to attack enemy electro-optical (EO) systems.

Figure 16, on the next page, shows the effect obscurants have on target acquisition and guidance systems from the visible through the millimeter wavelengths of the electromagnetic spectrum.

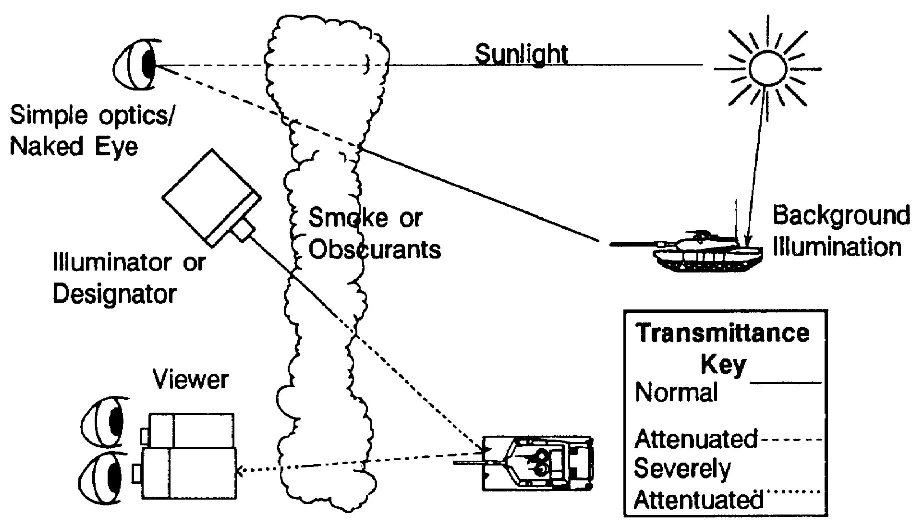

Figure 15. Obscurant effects on vision and viewers.

Sensors and Effects

On the AirLand battlefield, what is seen can be hit and killed. Precision-guided munitions and sophisticated sensors that provide new means of observation and detection have appeared on the battlefield. Smoke and other obscurants can degrade the effectiveness of sophisticated precision-guided weapon systems.

Target Visibility

When you conceal an object by smoke, a number of factors determine the degree of obscuration. Physical properties of the object, such as size, shape, color, brightness, and reflecting properties of various parts of the surface, determine the density of the smoke required for effective obscuration. The degree of illumination of the area, the background setting, and angle of observation have an important effect.

The overriding factor in smoke screen effectiveness is the total concentration of smoke and the path and length of the smoke cloud between the observer and the target. Thus, one observer may detect the

target, while a second observer may not, because of extended line of sight through the smoke to the target.

When considering target visibility, it is important to distinguish between the sighting of an object and identifying that object as an enemy target. The prevention of detection is the severest test of a smoke cloud. Although most detection efforts in the past were in the visible spectrum, modern technology has extended the useful spectrum beyond the visible wavelengths.

Infrared (IR) **rays** have properties similar to those of visible light. However, IR rays may readily pass through materials that lessen visible light (for example, IR rays pass more readily through the atmosphere than visible light, even through light rain, snow, and fog). Night vision devices use the IR rays produced by or reflected from an **object.** Active IR is radiation produced by an illumination source and then reflected from an object; heat radiates from an object. IR radiation depends on the type of radiating material and its temperature. With an increase in temperature there is an increase in radiation. In hazy weather, IR devices can give a two- to four-fold increase in range over visible spectrum devices. In foggy weather, IR devices suffer a marked decrease in range, but are still superior to visual devices. Many of the restrictions noted for IR also apply to military laser range finders and seekers.

Sensors and Viewers

As a result of the development of IR and radar devices during World War II and subsequent technical advances, electronic sensors have supplemented conventional visual methods of target acquisition and aiming. The introduction of electronic techniques has also enhanced our ability to detect and attack targets at night and in adverse weather.

We can degrade the performance of electronic sensors by using obscurants (smoke and dust). Some of these devices can be rendered ineffective; others can be degraded significantly; still others will not be affected at all. However, to effect sensors we must use the right kind of obscurant at the right place, at

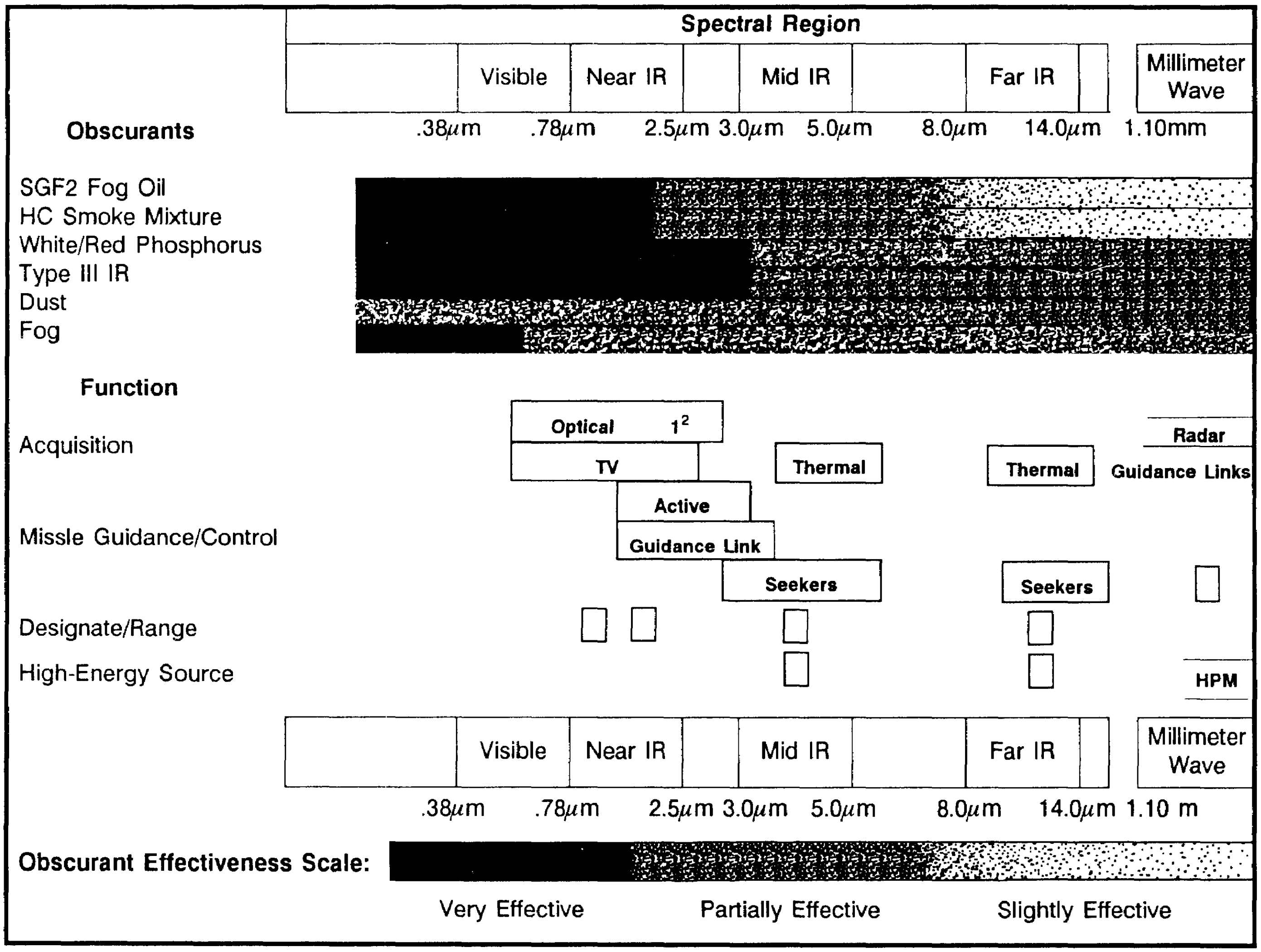

Figure 16. Obscurant effects on battlefield electro-optical devices.

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the right time, and in sufficient quantity.

The eye is the basic receiver for several types of EO sensors. Four sensors that rely on the eye are the naked eye itself, the telescope, the television viewer, and the image intensifier. Sensors can be active or passive depending on the mechanism they use to detect and intensify the images.

Operational Considerations

The eye, the telescope, the television viewer, and the image intensifier all require illumination of the target and its background. The sun, moon, stars, or illumination rounds may provide this illumination. The eye detects reflected light and is dependent upon the contrast between the brightness of the target and its background. The telescope improves the capability of the eye by enlarging the target image. Television viewers are used to provide viewpoints from distant, hostile, or awkward positions. Television viewers can also function as image intensifiers or to enhance contrast. Image intensifiers electronically magnify the light received, increasing it to a level the eye can see. Contrast enhancement electronically increases the brightness of the target, making it easier to see.

Passive sensors use available natural light. We use passive systems when the available light is sufficient to illuminate the target. An active viewer system consists of a viewer and an illuminator, which floods the target with light. Illuminators for different active viewing sensors include lasers, searchlights, or flares. We use active sensors when there is not enough light to illuminate the target.

Effects of Obscurants

Placing obscurants between the target and the viewer will degrade the performance of these sensors. Target acquisition and identification depend on the contrast between the target and its background and the brightness of the target. Smoke and dust will decrease this contrast and brightness by attenuating light reflected from the target. Rain, snow, fog, and haze will also degrade the performance of these systems. To use an obscurant against these sensors, place the obscurant in the line of sight between the target and the observer. Obscuration use in moonlight can also degrade the contrast of target and background. We can further degrade the contrast of a target with its background by the light from the sun that fails directly onto the obscurant and is then scattered into the line of sight. The amount of degradation depends on the position of the sun and the depth of the obscurant cloud. Degradation is greatest when both sun and target have about the same line of sight to the observer or viewer. Considerable degradation can also occur when the sun is directly behind the observer or viewer.

Thermal Viewers

Passive thermal viewers use the natural thermal radiation differences between target and background to form an image – hence the name thermal viewer. Another name for a thermal viewer is forward looking infrared (FLIR). These thermal viewer systems require no external source of radiation and can successfully operate on a dark night if the targets are sufficiently warmer or cooler than the background. The thermal viewer is used in fire control systems, in some thermal homing missiles, and for surveillance purposes.

Reducing the apparent contrast between the target and its background may degrade the effectiveness of the thermal viewer. Obscurants degrade sensor performance by attenuating the target radiation signature reaching the viewer. The thermal radiation produced by the cloud may also degrade performance of the sensor. The initial burst of a munition will also produce a hot spot of thermal radiation, possibly saturating or blinding the viewer for a few seconds. Such hot spots may also divert or decoy thermal-tracking missiles.

Most smoke attenuates thermal radiation less effectively than visual radiation, so more smoke is required to degrade thermal viewers; the relative amount depends on the agent employed. However, some smoke (for example, HC and fog oil) is not very effective against thermal viewers. High concentrations of WP and RP and black smoke are more effective against thermal viewers.

Command-Guided Missiles

Most command-guided missiles are command to line of sight (CLOS) missiles, which operate in one or more spectral regions. The oldest of CLOS missiles are visually and manually controlled, requiring the operator to track both the missile and its target, while simultaneously guiding the missile to the target (for example, the Soviet Sagger). Tracking the missile can be aided by putting a beacon on the missile. This guidance scheme has been relatively easy to defeat, since either the target or the missile can be obscured, and a miss results. In addition, the flash from an exploding HE or smoke munition could serve to distract the gunner, again resulting in a miss.

The next type of missile control is semiautomatic CLOS (for example, the Dragon). In this case, the operator or gunner only tracks the target; the missile is automatically guided. This reduces the burden on the gunner and increases the accuracy. However, to cause a miss it is only necessary to obscure either the missile beacon or the target; further, the sensor tracking the missile may be blinded for a short period of time by the flash of an exploding munition. Many systems using this type of guidance use a beacon and tracking sensor that operate in the near IR. With visual target tracking this presents no difficulty. However,

with the advent of thermal imagers a situation known as spectral mismatch can occur. In this case, and under obscured condition, it may be possible to see a target with the thermal imager but not to hit the target because of obscuration of the missile beacon.

A third type of guidance is automatic CLOS. Both target and missile are tracked automatically, usually by different sensors. This type of CLOS guidance is the most sensitive to obscuration, especially with sensors operating in the shorter wavelengths.

A more recent type of guidance command for CLOS missiles is beamrider guidance. Here, a gunner tracks the target either manually or automatically while illuminating the target with a beam of light. Usually this beam is provided by a laser, and most beamriders operate in the near and far IR spectrums. Most do not use the visible portion to prevent exposing the firing position. Sensors on the rear of the missile look back at the beam projector. These sensors track the beam, and the missile guides itself to the target. Beamrider guidance suffers from the same obscuration limitations as conventional CLOS missiles with a beacon. As a rule, the lasers used in beam projectors have more power than the equivalent beacon on a CLOS missile. As a result, the laser beam is harder to obscure.

Beamrider missiles are built so that the spectral mismatch is not the weak link in terms of susceptibility to obscuration. If you track a target using the visible portion of the spectrum, guidance is performed using either the IR or millimeter wavelengths. Similarly, if target track is carried out with a thermal imager, the missile is guided using a far IR or millimeter wavelength. In effect, the target-tracking element of the beamrider system is usually the most vulnerable to obscuration.

Most CLOS missiles receive guidance commands by a wire connecting the launcher and the missile. The wire is not susceptible to obscuration; however, severing the wire (for example, by shell fragments) will result in a miss. Some CLOS missiles receive guidance commands by a radio link in the radar or millimeter portions of the spectrum. These commands are difficult to degrade using conventional obscurants. Of more importance is the effect of the electromagnetic radiation emitted during an HE detonation. This radiation may cause the missile to miss its target. As a rule, it is easier to obscure the target tracker of a beamrider system than the laser beam that guides the missile. This target tracker is usually a viewer or a thermal viewer.

Obscuring the target tracker (viewer or thermal viewer) usually causes a miss and may even prevent the gunner from launching the missile if the target cannot be seen. The flash of an exploding munition behind the missile may blind the tracking sensors on the rear of the missiles, causing the missiles to miss the target.

Terminal Homing Missiles

This guidance is characterized by a missile with a seeker at the front that tracks the target and guides the missile to the target. There are two categories of terminal homing missiles: those that lock on the target before launch and those that lock on the target after launch. Missiles that lock on after launch are generally more susceptible to obscuration effects than missiles acquiring lock before launch. Terminal homing seekers operate in one or more of three modes: active, passive, or semiactive.

Most active seekers operate in the radar and millimeter wavelength regions. These seekers are not, as a rule, adversely affected by obscuration, although they may be blinded momentarily by the detonation of an HE or smoke munition. Passive seekers may operate in any spectral region. The most common seekers operate in the IR. Passive seekers operating in the visible or IR regions may be either imaging or nonimaging.

Passive imaging seekers have essentially the same susceptibility to obscuration as any imaging sensor, although far IR imaging seekers may look on a WP cloud that is hotter than the target and track the cloud as the target. This type of seeker may also be blinded by the flash from a detonating munition and therefore miss its target.

Nonimaging IR seekers often use two spectral bands. These two bands are used to discriminate between real and false targets (such as fires or hot rocks). These seekers can be decoyed by the difference in obscuration effects upon the two spectral regions. This difference may cause the seeker to think the target is a rock (and ignore the target) or to think a fire is the target (and attack the fire). Semiactive seekers use energy reflected from the target for tracking. Usually, the target is illuminated by a laser operating in the IR. Target illumination does not have to come from the launch point or site. This type of seeker may be defeated by obscuring the beam, either before or after it is reflected from the target. If obscuration is placed closer to the laser than to the target, sufficient laser energy may be scattered by the cloud to cause the missile to track the obscurant cloud rather than the real target.

Radar and Millimeter Wave Sensors

We can use radar and millimeter wave sensors to determine the position and/or velocity of the target. Since these form only poor images of the target, we do not get recognition and identification in the usual manner.

Dust and conventional smokes do not effectively degrade radar and millimeter wavelength sensors. However, other highly effective counter-

measures exist. A munition dust cloud does produce obscuration for a few seconds when the burst is in, or very near, the line of sight. In the far term, we will use millimeter wave obscurants, projected onto enemy positions, to degrade radar and millimeter wave sensors.

Directed-Energy Weapons

Directed-energy weapons differ in operation and effect from all other weapons. They include lasers; high-power microwaves; particle beams; and non-nuclear, directed electromagnetic pulse (EMP). Except for lasers and high-power microwaves, directed-energy weapons are in the early stages of development.

Directed-energy weapons transmit energy at or near the speed of light in the form of subatomic particles or electromagnetic waves. This energy impacts on the target as heat or shock. Directed-energy weapons can damage soft targets and soft components of hard targets, such as lenses, electrical and electronic components, and eyes. New equipment will have built-in defenses against known directed-energy weapons. We will fit older equipment with protective devices. In the near term, we will use smoke and obscurants to reduce the impact of attack by directed-energy weapons.

Lasers

As of 1990, no army is known to have laser devices fielded for use specifically as weapons. However, laser target designators and range finders are in the inventories of all major armies, and their numbers are increasing. Any of these laser devices can be used as a weapon. Laser weapons are effective against optical and EO systems: specifically, eyes and fire-control sights.

Laser range finders are used on the M60A2, M60A3, and Ml series tanks and our artillery units. Artillery fire support teams for airborne, ranger, and special forces units use the lightweight target designator; fire support teams for mechanized, infantry, and air-assault units use the ground-locating laser designator in either the ground-mounted or vehicle-mounted mode; and all fire support team members use the GVS-5, binocular-type, laser range finder.

Additionally, artillery survey parties use laser devices for surveying gun positions. Scout platoons are equipped with GVS-5 laser range finders. USAF and Navy aircraft (F4, A7, F111, F105, F16, and A6 aircraft) may also carry laser target designators. Although these are not intended as weapons, accidental eye damage can occur if someone moves into a laser beam path and looks directly at the beam, or a laser beam reflects off a shiny surface into someone's eyes. A high-power laser beam striking in front of an EO device such as night vision devices or thermal imaging systems may also damage components and electrical circuits or cloud the lens.

To avoid engagement by laser weapon systems, use artillery, mortars, or direct-fire weapons to suppress known or suspected laser device locations. Smoke can temporarily defeat some laser devices. When operating within the enemy's line of sight, protect vulnerable systems by providing them cover or concealment. Cover sensor systems when not in use. If the mission requires movement, block the line of sight between friendly forces and enemy location with smoke, and/or use routes with minimal exposure time. Shoot-and-move tactics help prevent friendly positions from being pinpointed and targeted by laser devices. When searching with optical or EO devices, use as few as possible. Protect unused devices until they are needed.

High-Power Microwaves

Electric ammunition fuzes and many missile electronic guidance systems can be damaged by microwaves. Unprotected soldiers may experience warmth, pain, headaches, fatigue, weakness, and dizziness.

Terrain masking offers some protection from microwaves. The high-power microwaves operate in the millimeter wave spectrum; thus, smoke and dust have virtually no effect and should not be used solely to degrade their performance. A munition dust cloud does produce obscuration for a few seconds when the burst is in, or very near, the line of sight. In the far term, we will use projected millimeter wave obscurants onto known or suspected enemy microwave weapon locations to block or absorb the energy at its source.

Particle Beams

A particle beam is a directed flow of atomic or subatomic particles transmitted in a series of short pulses; it delivers large quantities of energy to targets in millionths of a second. The beam penetrates bad weather and smoke better than a laser beam and is much more destructive. The particle energy impacts in the form of heat, which melts or fractures the target. Particle beams may also create gamma and X ray when they strike metal.

Millimeter wave obscurant and type 3 IR obscurant may lessen some of the energy but will not be more than slightly effective. If a particle beam weapon is developed for ground combat, use the defensive measures taken against other direct fire weapons.

Electromagnetic Pulses

An EMP is a surge of electromagnetic radiation generated by a nuclear detonation or a pulse generator. An EMP travels hundreds of miles in a fraction of a second and can damage or destroy unshielded electrical equipment.

To protect electronic equipment against EMPs and microwaves, all cable and entry points must be shielded. The equipment should be completely encased in metal. Extra equipment or equipment not needed at the moment should be disconnected; small, electronic items should be placed in empty ammunition cans. Millimeter wave obscurant and type 3 IR obscurant may lessen some of the energy but will not be more than slightly effective.

Appendix C

Means of Delivery

Smoke can be delivered to the target in numerous ways, from artillery and aircraft to grenades and generators. Your choice of delivery means will be determined by the amount of smoke needed, the distance to the target, and the availability of resources.

Artillery Munitions

The field artillery provides effective systems for rapidly placing smoke on distant targets. They use HC, WP, and RP projectiles.

Use artillery-delivered smokes to–

- Obscure enemy observers and target acquisition and guidance systems (for example, CLOS ATGMs).
- Isolate or segregate enemy formations.

In projecting smoke onto the battlefield, the field artillery uses three types of missions: quick smoke, immediate smoke, and special smoke.

Quick Smoke

The objective of a quick smoke mission is to obscure the enemy's vision or to conceal maneuver elements. The quick smoke mission equates to the normal HE adjust fire mission. Obscuring the enemy is required, but the urgency of the situation does not require immediate smoke procedures. Use a quick smoke mission to screen a small area of 150 to 600 meters for a period of 4 to 15 minutes.

Immediate Smoke

The objective of an immediate smoke mission is to obscure the enemy's vision immediately. Use an immediate smoke mission to obscure a point of 150 meters or less within 30 seconds for 1 1/2 to 5 minutes.

Special Smoke

The objective of a special smoke mission is to conceal a large area to protect or conceal maneuver forces for an extended period of time. Consider a special smoke mission when the size of the cloud makes a quick smoke mission impractical. This type of screen can vary from 400 to 2,400 meters in length.

Table 11 lists characteristics of artillery smoke munitions.

Table 11. Characteristics of artillery smoke munitions.

Type Round	Delivery System	Time to Build Effective Smoke	Average Burn Time	Range
WP	155 mm	½ min	1 to 1½ min	18,000 m
HC		1 to 1½ min	4 min	
WP	105 mm	½ min	1 to 1½ min	11,200 m
HC		1 to 1½ min	3 min	

Mortar Munitions

Mortars can provide good initial smoke coverage because of their high rate of fire, but their small basic load limits the size and duration of the cloud they can provide. They are the most rapid and effective indirect smoke delivery means available to the maneuver commander.

Use mortar-delivered smokes to obscure enemy observers and target acquisition and guidance systems, such as CLOS ATGMs, and to isolate or segregate enemy formations.

Table 12, on the next page, lists characteristics of mortar-delivered smoke munitions.

Table 12. Characteristics of mortar-delivered smoke munitions.

Type Round	Delivery System	Time to Build Effective Smoke	Average Burn Time	Range Min/Max
WP	4.2 in	½ minute	1 minute	920/5,650 m
WP	81 mm	½ minute	1 minute	70/4,595 m
WP	60 mm	½ minute	1 minute	75/1,629 m

Rockets

AH/1S and AH-60 helicopters can deliver smoke munitions using the Hydra 70 rocket launcher system. The Hydra 70 fires a 2.75-inch rocket, which has a WP warhead (M156).

Use helicopter-delivered rockets to—

- Identify/mark targets for CAS aircraft and artillery.
- Obscure enemy observers and ATGM and air defense (AD) systems.

Table 13 lists characteristics of attack helicopter-delivered smoke rockets.

Table 13. Characteristics of helicopter-delivered smoke rockets.

Munition	Cloud Width	Cloud Duration
M156 WP Warhead	50 m	1 to 1½ minutes

Aircraft-Delivered Smoke

The M52 helicopter smoke generating system is still in the US Army inventory, but in January 1982 the Army Materiel Command (AMC) type classified it as Standard B. However, it is a very effective smoke delivery method against a low-technology enemy or one with limited air defense assets. The system contains a fog oil tank, an electrical pump to transfer fog oil to the spray apparatus, and jets on a spray ring to direct the fog oil into a hot exhaust. There, the oil is vaporized into a thick, dense, white smoke.

The UH1 helicopter is the airframe for this system. **It is effec**tive when the UH1 flies at speeds less than 90 knots and at heights not to exceed 50 feet; this makes the helicopter extremely vulnerable to air defense systems. This system has application for uses in various low-intensity conflict operations (for example, counternarcotics operations, peacetime contingency operations, and counterinsurgency operations) when the enemy has relatively few air defense systems.

Table 14 lists the characteristics of aircraft-delivered smoke.

Table 14. Aircraft-delivered smoke characteristics.

System	Type Aircraft	Cloud Length	Cloud Duration
M52 Smoke Device	Low Performance	40 m x 6,580 m	3 to 10 minutes

Rifle Grenades

Rifle grenades can deliver smoke to point and area targets up to 350 meters away from individual soldiers. The M203 and M79 grenade launchers and the MK19 automatic grenade launcher all can fire smoke grenades. The smoke cartridges include the M713 red smoke, M715 green smoke, and M716 yellow smoke cartridges.

Use rifle grenades to–

- Obscure snipers, enemy fighting positions, and heavy weapon emplacements.
- Provide immediate suppressive smoke to degrade enemy weapon guidance links or tracking.
- Conceal the movement of small tactical units (squad or smaller).

Table 15, on the next page, lists the characteristics of the 40-millimeter grenade launcher.

Table 15. Characteristics of 40-mm grenade launcher.

Cartridge for 40-mm Grenade Launcher	Type	Color	Burn Time
M676	Canopy	Yellow	60 to 90 seconds
M680	Canopy	White	60 to 90 seconds
M682	Canopy	Red	60 to 90 seconds
M713	Marking	Red	17 to 30 seconds
M715	Marking	Green	17 to 30 seconds
M716	Marking	Yellow	17 to 30 seconds

Smoke Pots and Smoke Hand Grenades

Smoke Pots

Smoke pots produce large volumes of white or grayish-white smoke for extended periods. They are the small-unit commander's primary means of producing small-area screening smoke. Pots are necessary for employing smoke on water, as the M4A2 floating HC smoke pot is the only smoke-producing system that floats.

Emplace smoke pots by hand, drop them from vehicles or helicopters, use them as a field expedient, or fasten them to the outside of armored vehicles. Ignite smoke pots either manually (M4A2 and ABC-M5) at the emplacement site or electrically from remote positions (ABC-M5 only). The pots can be fired individually, simultaneously, or in a long-burning chain. Smoke pots are used by all services.

Table 16 lists the characteristics of US Standard A smoke pots.

Smoke Hand Grenades

Smoke hand grenades produce either white smoke or colored smoke for short periods of time. Because they only produce small amounts of smoke, smoke hand grenades are not effective for screening smokes for units larger than one or two squads. Emplace smoke hand grenades by hand or manually ignite them with a trip wire. This technique is effective to deceive the enemy with a diversion. The average soldier can throw a grenade 30 to 35 meters. White smoke grenades are most often used to conceal individual vehicles; colored smoke grenades are used to mark or spot positions. All services have and use smoke grenades

Table 17, on the next page, lists current smoke hand grenades and their characteristics.

Table 16. Characteristics of Standard A smoke pots.

Type	NSN	Ignition	Burn Time (Min)	Weight (lb)		Possible Uses	Duration (Minutes)
				Filling	Total		
ABC-M5 30-1b HC	1365-00-598-52077	Ignite by manual matchhead or electrical squib	12	31	33	Small-area screens Small smoke curtains (Ground-based only)	12 to 22
M4A2 HC Floating	1365-00-598-5220	Ignite by manual fuze only Issued w/M207A1 fuze	10	27½	11	Small area screen. Small smoke curtains (ground based or over rivers, small streams, and other operations that require floating capability): may be helicopter-delivered	10 to 15

Warning

The M4A2 smoke pot must be vented for five minutes within 24 hours prior to ignition. Vent each M4A2 pot by folding back the tape from at least two of the emission holes.

Table 17. Smoke hand grenade characteristics.

Type	Smoke Color	NSN	Weight (lb)	Possible Use	Duration (Sec)
AN-M8 HC	White	1330-00-219-8511	1.6	Marking or Small-Area Screens	105 to 150
M18	Red	1330-00-289-6852	1.2	Marking	50 to 90
	Green	1330-00-289-6851			
	Yellow	1330-00-289-6854			
	Violet	1330-00-289-6853			

Generators

The mechanical smoke generator is a device that vaporizes smoke generator fog oil number 2 (SGF2). The vapor released condenses in the air as a white smoke. Currently, mechanical smoke generators are the only large-area smoke devices type classified Standard A. Table 18 lists generator systems and their characteristics.

Table 18. Smoke generator characteristics.

System	Prime Mover	Mobility	Obscuration Spectrum	On-Board Duration
M3A4	M998 HMMWV	Static	Visual, Near IR	1 hr
M157	M1037 HMMWV M1059 SG Carrier	Mobile	Visual, Near IR	48–96 min
XM56	M1037 HMMWV	Mobile	Multispectral	Developmental
LAMPSS	Developmental (Fully Tracked)	Mobile	Full Spectrum	Developmental

Armored Vehicle Grenade Launchers

Three types of launchers for tanks and armored reconnaissance vehicles are designed to rapidly generate small amounts of smoke to conceal or screen individual vehicles. The vehicle commander launches the grenades as soon as he is fired upon, so the driver can take evasive action behind the smoke. The launchers fire either AN-M8 HC and M34 WP grenades (M176 launchers) or L8A1 RP and M76 IR grenades (M239 launchers).

Table **19 gives the characteristics** of these self-defense grenades.

Table 19. Vehicle self-defense grenade characteristics.

Type		Total Grenades	Distance From Vehicle	Firing Arc	Time To Build Effective Smoke	Average Burn Time
Launcher	Grenade					
M176	HC, WP	8	30–40 m	90°	5 sec	90 sec
M226	HC	8	30–40 m	90°	6 sec	90 sec
M239	RP and Type III IR	12	24–30 m	110°	2 sec	1–3 min

Vehicle Engine Exhaust System

The VEESS is a vehicle-mounted smoke system that produces smoke by vaporizing fuel with the exhaust system. Vehicles that currently have the VEESS include the AVLB, CEV, M88A1, M60, Ml, M2, and M3 families of combat vehicles.

In a heavy brigade-size combined arms force scenario, the VEESS provides a significant reduction (up to 20 percent) in the vulnerability of MIs, M2/3s, and Improved Tow vehicles. When our forces use the VEESS, the lethality of BMPs from the 1- to 2-kilometer range decreases as much as 80 percent. In summary, the lethality of enemy tanks decreases about 20 percent at close range. Self-defense smoke provides significant protection in the close battle.

Safety

Safety with smoke and smoke delivery systems depends primarily on two things: characteristics of the smoke and safety for the weapon or delivery systems. Tables 20 and 21 identify safety constraints and measures for US smoke and delivery systems.

Table 20. Smoke safety constraints.

Smoke Agent	Problem/ Concern	Response/Prevention
SGF2	Can cause pneumonia	Wear respiratory protection (mask) when in high concentrations of oil smoke or after 4 hours in low concentrations of oil smoke (haze)
HC	Carcinogenic	Wear respiratory protection at all times when exposed to HC smoke
WP, RP	Explosive; Can cause severe burns; Causes respiratory irritation	Do not use near friendly troops
Violet Smoke	Carcinogenic	Same as for HC

Table 21. Smoke delivery systems safety.

System	Problem	Response/Prevention
Artillery, Mortars, Rockets	Munitions are explosive. All can produce friendly casualties	Do not use near friendly troops
M239 Grenade Launcher	RP and IR grenades explosive	Safety radius of 50 meters for exposed troops in combat, 100 meters in training
M203 Grenade Launcher	Grenades explosive	Do not use near friendly troops
M18 Grenade AV-M8 HC Grenade	Burning device	Do not pick up or move when lit; wear gloves and eye protection when igniting; safety radius of 5 meters from friendly troops
M5, M5 Smoke Pots	Burning device	Same as M18 grenades. Plus: When igniting, keep head well to one side of the top of the pot and out of the way of sparks or flame. DO NOT use the pull ring or safety pin to lift a pot. Vent M4A2s. Safe distance for electrical ignition of M5 is 50 feet.
Smoke Generator	Vaporized SGF2 (See Table C-10)	Exhaust of smoke is very hot. Safety radius of 5 meters. No smoking around generator. Keep fire extinguisher within arm's reach; always add fuel from the fuel tank side; store gas can at least 15 feet from running generator. DO NOT touch engine head with bare hands.

Appendix D

US Smoke Organizations and Capabilities

Most chemical command and control headquarters are Reserve Component organizations. In the active Army, there are few battalion-level chemical organizations. Most corps and division-level smoke assets are company-sized elements or smaller. Task organizing platoons from these companies provide the commander a mission-tailored mix of assets normally associated with battalion and higher levels.

This appendix describes the capabilities, limitations, and structure of chemical command and control headquarters, smoke units, and chemical unit task organizations.

Chemical Command and Control Headquarters

The two major chemical command and control headquarters are the corps chemical brigade (HHD) (TOE 03-4721) and the corps chemical battalion (HHD) (TOE 03-476L).

Chemical Brigade

Chemical brigades normally are assigned one to each corps. Each chemical brigade is composed of a headquarters and headquarters detachment (HHD) and two to five chemical battalions. The brigade can provide limited administrative support, logistics, mission/operations planning, and execution supervision for the chemical battalions. The chemical brigade does not have organic supply and transportation assets for sustaining its assigned battalions.

Chemical Battalion

Chemical battalions usually are assigned to a chemical brigade at corps, or one per TAACOM. Each chemical battalion is composed of a headquarters and headquarters detachment and two to five chemical companies. The battalion can provide limited administrative support, logistics, mission/operations planning, and execution supervision for the chemical companies. The chemical battalion does not have a support platoon; therefore, it has no organic supply and transportation assets for sustaining its assigned companies.

Smoke Generator Units

The major smoke generator unit tactical organizations are–

- Corps Chemical Company (SG) (Motorized) (TOE 03-067J).
- Corps Chemical Company (Smoke/Decon) (TOE 03-257J).
- Corps Chemical Company (SG) (Mechanized) (TOE 03-077J).
- Heavy Division Chemical Company (Mechanized Smoke Platoon) (TOE 03-387).
- Division Chemical Company (Airborne/Air Assault) (TOE 03-027J500/03-057L).
- Chemical Company (Smoke/Reconnaissance/Decon), Armored Cavalry Regiment (TOE 03-377L).

There are two different types of motorized systems and one mechanized smoke generator system. The M3A4 and the M157 are motorized, and the M1059 is mechanized.

Motor smoke units equipped with the M3A4 have 36 to 48 smoke generators mounted on 18 to 24 M998 series HMMWVs or M151 series 1/4-ton trucks with trailers. These smoke systems provide stationary smoke only. Depending on terrain, the company is 100-percent mobile and is completely air-transportable.

Motor smoke units equipped with the M157 have 36 to 48 smoke generators mounted on 18 to 24 M1037 HMMWVs. This company, also, is 100-percent mobile and is completely air-transportable.

Mechanized smoke units equipped with the M1059 smoke generator carrier have six (heavy division company) or seven (mechanized smoke company) M1059s per platoon. This element is 100-percent mobile on any terrain and is completely air-transportable.

Corps Chemical Company (SG) (Motorized)

The motorized smoke generator company provides large-area smoke support for tactical and rear operations. The two platoons of the motorized smoke company have three squads each. There are 24 smoke generators per platoon. Each platoon (if weather, terrain, and the situation are favorable) can support up to a maneuver brigade.

Corps Chemical Company (Smoke/Decon)

The corps smoke/decon chemical company or dual-purpose company provides smoke and decontamination support to the light infantry division or units located in the division or corps rear area. This company has four dual-purpose platoons. Each of the four platoons can provide both smoke and decontamination support. However, the platoon can do only one mission at a time. Each platoon has two dual-purpose squads and one resupply squad. The company has 48 smoke generators — 12 per platoon

The most difficult task of this company is the transition from decontamination to smoke support (or the reverse). This transition can be carried out at the company CP or in the BSA.

corps Chemical Company (SG) (Mechanized)

The mission of the chemical company (smoke generator-mechanized) is to provide smoke concealment for maneuver units and other critical areas. This company was developed because motorized companies lack the necessary armor protection and mobility to operate forward to support close operations in mid- and high-intensity conflict. It is organized into three smoke platoons. Each platoon has 14 smoke generators. (Two generators are mounted on each armored vehicle.) The seven vehicles form seven mobile point sources.

Heavy Division Chemical Company (Mechanized Smoke Platoon)

The smoke platoon of the chemical company (heavy division) gives the division a large-area smoke capability. It also provides limited site selection for decontamination squads. The platoon has six M1059 smoke generator systems. Each of the two smoke squads has three M1059s with six smoke generators per squad.

Division Chemical Company (Airborne/Air Assault)

This company provides smoke and decontamination support to the airborne or air assault division. This company has three dual-purpose platoons. Each of the three platoons can provide both smoke and decontamination support. However, the platoon can do only one mission at a time. Each platoon has two dual-purpose squads and one resupply squad. The company has 36 generators – 12 per platoon.

The most difficult task of this company is the transition from decontamination to smoke support (or the reverse). This transition can be carried out at the company CP or in the BSA.

Chemical Company (Smoke/Recon/Decon) Armored Cavalry Regiment

This company provides smoke and decontamination support to the armored cavalry regiment. The company has one dual-purpose platoon. Unlike other dual-purpose platoons, this platoon has seven M1059 smoke generator systems. The platoon can provide both smoke and decontamination support. However, the platoon can do only one mission at a time. The platoon has two dual-purpose squads and one resupply squad, with a total of 14 smoke generators.

Chemical Unit Task Organizations

The three unique chemical unit task organizations are–

- Chemical-engineer task force.
- Chemical company team.
- Chemical battalion task force.

Chemical-Engineer Task Force

The chemical-engineer task force attaches one or more smoke or dual-purpose chemical platoons to the division engineer battalion. This provides a habitual association for logistical support for the chemical platoons and is particularly useful when the platoon is supporting obstacle emplacement or covering force operations.

Chemical Company Team

The chemical company team attaches one or more platoons to a chemical company for specific missions. For example, a smoke platoon from a corps motorized smoke company could be attached to a heavy division chemical company for command and control during a particular mission.

Chemical Battalion Task Force

The chemical battalion task force attaches one or more platoons or companies to a chemical battalion for specific missions. Every smoke company in a corps chemical brigade could be attached to a particular chemical battalion when that battalion is supporting the corps main effort. For example, if a division had to conduct a river crossing as part of the corps scheme of maneuver. The corps commander might task organize most of his smoke generator companies under one battalion for direct support of this mission.

Capabilities

Tables 22 and 23 show smoke platoon area coverage based on the type of platoon and the number and types of generators or point sources.. The coverage is given in kilometers; and the prime movers are listed for the generators.

Table 22. Smoke platoon coverage—mobile.

Type of Unit	SG & Prime Mover	No. of Point Sources	Average Smoke Cloud Coverage (in Meters)			
			Crosswind Width		Downwind Depth	
			Haze	Blanket	Haze	Blanket
Corps Mechanized Smoke Plt	M1059	7	600–1,500	550–1,300	100–3,600	50–1,400
Division Mechanized Smoke Plt	M1059	6	550–1,400	550–1,200	100–3,600	50–1,400
Corps Smoke/Decon Plt	M157 & M1037	6	550–1,400	550–1,200	100–3,600	50–1,400
ACR Smoke/Decon Plt	M1059	6	550–1,400	550–1,200	100–3,600	50–1,400
Corps Motor Smoke Plt	M157 & M1037	12	1,100–2,800	1,00–2,400	100–3,600	50–1,400

Table 23. Smoke platoon coverage—stationary.

Type of Unit	SG & Prime Mover	No. of Point Sources	Average Smoke Cloud Coverage (in Meters)			
			Crosswind Width		Downwind Depth	
			Haze	Blanket	Haze	Blanket
Corps Motor Smoke Plt	M3A4 & M151	24	1,000–3,400	500–1,700	600–10,000	600–10,000
	M3A4 & M998	12	500–1,700	300–900	600–10,000	600–10,000
Corps Smoke/Decon Plt	M3A4 & M988	6	300–900	100–500	600–10,000	600–10,000
Div (Abn) Smoke/Decon Plt	M3A4 & M988	6	300–900	100–500	600–10,000	600–10,000
Div (AA) Smoke/Decon Plt	M3A4 & M151	6	300–900	100–500	600–10,000	600–10,000

Smoke Support Sustainment Planning Tables

The tables in this appendix provide smoke pot spacing guidance and ammunition and fuel consumption data. Use the tables to determine ammunition or fuel sustainment requirements for smoke missions.

Base your ammunition consumption planning on target size and smoke duration. Base fuel consumption planning on smoke unit structure, smoke duration, and fuel delivery packaging.

Smoke Pot Consumption

Table 24 is the spacing guide for smoke pots. When using Table 23 to determine actual spacing requirements, round up all answers (decimals) to the next larger whole number.

Table 25, below and on the facing page, is the smoke pot consumption guide. To use this table, you must know the length of the target area in meters and the spacing between pots in meters, plus how long the target must be smoked.

Table 24. Smoke pot spacing guide.

Wind Speed		Temp Gradient	Terrain	Spacing (Meters)		Meters to Target
Kmph	Knots			Haze	Blanket	
1–14	1–7	All	Open or Water	50	25	250
		Stable	Wooded	60	30	300
		Unstable or Neutral		70	35	350
15–25	8–13	All	Open or Water	40	20	200
			Wooded	50	25	250
26–32	14–17	All	Open or Water	30	15	150
			Wooded	40	20	200

Table 25. Smoke pot consumption guide. (Part 1 of 2)

Number of Smoke Pots Needed To Produce Smoke for a Mission												
Spacing	15m			20m			25m			30m		
Line Length / Smoke Time	100m	500m	1,000m	100m	500m	1,000m	100m	500m	1,000m	100m	500m	1,000m
15 min	12	51	102	9	13	77	8	32	62	6	27	51
30 min	24	102	204	18	78	153	15	63	123	12	48	102
1 hr	48	204	612	36	156	306	30	126	246	24	108	204
3 hr	144	612	1,224	108	468	918	90	378	738	72	324	612

Continued

Enter the table from the left–smoke time. Locate the spacing between pots at the top of the table. Under the spacing find your target length. The cell where this column and the smoke time row intersect contains the number of pots needed.

Fuel Consumption Tables

Use Tables 26 and 27 to determine fog oil and MOGAS consumption for smoke generators. These tables are based on normal consumptions of a smoke generator platoon running all generators simultaneously. When a crew operates a single M3A4 or M157 smoke generator, multiply the planning figure by 0.5.

Table 26. Fog oil consumption in gallons and [drums].

Platoon Type	1 hr	2 hr	4 hr	6 hr	24 hr	48 hr
Motor Smoke (24 Generators)	1,200 [22]	2,400 [44]	4,800 [88]	7,200 [131]	28,800 [524]	57,,600 [1,048]
Mechanized (7 M1059 Systems)	700 [13]	1,400 [26]	2,800 [51]	4,200 [77]	16,800 [306]	33,600 [611]
Dual Purpose (12 Generators)	600 [11]	1,200 [22]	2,400 [44]	4,800 [88]	7,200 [131]	28,800 [524]
Heavy Division Smoke Plt (6 M1059 Systems)	600 [11]	1,200 [22]	2,400 [44]	4,800 [88]	7,200 [131]	28,800 [524]

Numbers in brackets = Drums One drum = 55 gallons

Table 27. MOGAS consumption in gallons and .

Platoon Type	1 hr	2 hr	4 hr	6 hr	24 hr	48 hr
Motor Smoke (24 Smoke Generators)	72 [15]	144 [29]	216 [44]	864 [173]	1,728 [346]	3,456 [692]
Mechanized Smoke (14 Smoke Generators)	42 [9]	84 [17]	168 [34]	252 [51]	1,008 [202]	2,016 [404]
Dual Purpose (12 Smoke Generators)	36 [8]	72 [15]	144 [29]	216 [44]	864 [173]	1,728 [346]
Heavy Division Smoke Plt (12 Smoke Generators)	36 [8]	72 [15]	144 [29]	216 [44]	864 [173]	1,728 [346]

Numbers in brackets = Cans
1 Can = 4.5 gallons in a 5-gallon can

Table 25 continued. (Part 2 of 2)

Number of Smoke Pots Needed To Produce Smoke for a Mission												
Spacing	40m			50m			60m			70m		
Line Length / Smoke Time	100m	500m	1,000m	100m	500m	1,000m	100m	500m	1,000m	100m	500m	1,000m
15 min	6	21	39	5	17	32	5	14	27	3	12	23
30 min	12	42	78	9	33	63	9	27	48	6	24	45
1 hr	24	84	156	18	66	126	18	54	108	12	48	90
3 hr	72	252	468	54	198	373	54	162	324	36	144	270

Ammunition Consumption Tables

Use Tables 28 through 31, below, to determine consumption rates for artillery, and mortar munitions. Start with the wind speed, rate of fire, (or weapon and target size) and duration of smoke requested, and use the table to discover the number of rounds required for the mission.

Table 28. Quick smoke consumption data—155-mm smoke shell.

Fire for Effect—Rounds Per Tube													
Wind Speed in Knots	Rate of Fire	Duration Requested by Forward Observer (in Minutes)											
		4	5	6	7	8	9	10	11	12	13	14	15
5	1 rd/min	2	2	3	3	4	4	5	5	6	6	7	7
10	1 rd/30 sec	2	3	4	5	6	7	8	9	10	11	12	13
15	1 rd/20 sec	3	4	6	7	9	10	12	13	15	16	18	19

Table 29. Quick smoke consumption data—155-mm WP shell.

Fire for Effect—Rounds Per Tube															
Wind Speed in Knots	Rate of Fire	Duration Requested by Forward Observer (in Minutes)													
		2	3	4	5	6	7	8	9	10	11	12	13	14	15
14515	1 rd/min	3	4	5	6	7	8	9	10	11	12	13	14	15	16
10	1 rd/30 sec	4	6	8	10	12	14	16	18	20	22	24	26	28	30
15	1 rd/20 sec	6	9	12	15	18	21	24	27	30	33	36	39	42	45

Table 30. Smoke ammunition consumption —artillery battery.

Weapon (Target Size)	Duration of Mission	Total Rounds
155-mm HC (2,800 m x 50 m)	5 min	16
	10 min	40
	15 min	56
155-mm WP (1,200 m x 50 m)	2 min	24
	5 min	48
	15 min	128
105-mm WP (450 m x 35 m)	2 min	18
	5 min	36
	15 min	96

All figures assume 9 kmph crosswind.

Table 31. Smoke ammunition consumption —mortar platoon.

Weapon (Target Size)	Duration of Mission	Total Rounds
107-mm WP (600 m x 40 m)	2 min	12
	5 min	27
	15 min	72
81-mm WP (300 m x 35 m)	2 min	12
	5 min	27
	15 ;min	72
60-mm WP (225 m x 35 m)	2 min	12
	5 min	27
	15 min	72

All figures assume 9 kmph crosswind.

Appendix F

Weather and Terrain

Environmental factors and terrain affect smoke cloud behavior. Steering winds, temperature gradients and the type of terrain are important for accurately predicting smoke cloud travel.

Weather

Meteorological conditions that have the most effect on smoke screening and munitions expenditures (including the deployment of smoke generators) include wind, temperature gradients, humidity, precipitation, and cloud cover.

Wind

The weather condition with the greatest impact on smoke operations is wind. Both wind direction and wind speed play a significant role in almost everything that deals with smoke operations. These factors are important in estimating equipment, munitions, and fog oil requirements for a smoke operation.

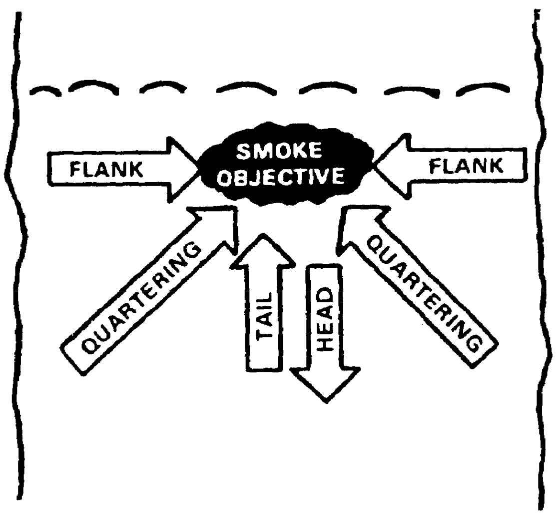

Figure 17. Classification of wind directions.

Wind direction determines where smoke must be released and where it will travel. Basically, there are four different types of wind directions that affect smoke operations: head winds, tail winds, flanking winds, and quartering winds. Favorable wind directions in relation to the smoke objective are the tail, quartering, and flanking winds (see Figure 17).

Head winds are those blowing from the smoke objective directly toward the smoke source and are unfavorable for smoke generator operations.

Tail winds, the most favorable for smoke operations, blow toward the smoke objective from behind the smoke source.

Flanking winds blow directly across the smoke objective and the smoke source and are generally favorable for smoke operations.

Quartering winds blow between the other winds toward the smoke objective.

It is important to make the distinction between those surface wind directions just discussed and steering winds. Steering winds occur between 6 meters and 200 meters above the earth's surface. They are the winds that actually carry the smoke and determine the direction of smoke travel.

Wind speed has as much influence on smoke behavior as wind direction has. Low wind speed or calm conditions allow smoke to remain in the target area for a longer period of time. In addition, some types of smoke behave differently at different wind speeds. For example, WP tends to pillar if winds are less than 9 knots (17 kilometers per hour). HC smoke rises when the wind speed is less than 4 knots (7 kilometers per hour), and it is torn apart by wind speeds over 13 knots (24 kilometers per hour). Smoke from mechanical smoke generators may be effective in higher wind speeds because of the great volume produced.

Temperature Gradients

Temperature, by itself, has no direct relationship with making effective smoke. It does, however, have an indirect relationship, which is a result of temperature gradients. Temperature gradients are determined by comparing the air temperature at .5 meter above the ground with the air temperature at 4 meters. Three types of temperature gradients influence smoke: unstable (lapse), neutral, and stable (inversion) (Figure 18, next page).

Unstable. An unstable (lapse) condition exists when air temperature decreases with an increase in altitude. This condition is characterized by vertical air currents and turbulence. Thus, smoke tends to break up and become diffused. Lapse conditions are best for producing smoke curtains.

Neutral. A neutral condition exists when air temperature shows very little or no change with an increase in altitude. Neutral conditions also exist when the wind speed is greater than 9 kilometers per hour. Under this condition, vertical air currents are very limited. Neutral conditions are best for smoke hazes and smoke blankets; however, this is not the most favorable temperature gradient for smoke.

Stable. A stable (inversion) condition exists when the air temperature increases with an increase in altitude, This condition greatly limits vertical air currents. A smoke cloud produced during inversion conditions lies low to the ground and may reduce visibility at ground level. Inversion conditions are excellent for smoke hazes and smoke blankets but only if there is enough wind to carry the smoke over the target area.

Humidity

Practically all smoke particles absorb moisture from the air. Moisture increases particle size and density and makes the smoke more effective. Most smoke munitions produce a denser (thicker) smoke when the humidity is high than when it is low; therefore, high humidity is generally favorable for smoke employment (Table 32).

Precipitation

Since light rains decrease visibility, less smoke gives concealment during these rains. Heavy rains and snow reduce visibility; therefore, smoke is rarely needed for concealment during those conditions. When used during periods of precipitation, smoke tends to remain close to the ground and spread out over a large area.

Cloud Cover

The amount of clouds in the sky gives an indication of how smoke will act on the battlefield. The general rule is when the sky is covered with clouds, the atmosphere is relatively stable, and the conditions are generally favorable for making smoke.

Table 33, on the next page, provides a summary of favorable and unfavorable conditions for smoke production.

Table 32. HC and WP smoke yields in various humidities.

Relative Hiumidity	HC	WP
%	Effectiveness (Percentage)	Effectiveness (Percentage)
0	100	100
10	146	353
20	152	372
30	159	391
40	173	411
50	189	434
60	211	465
70	240	510
80	325	588
90	572	785

Time of Day and Weather Conditions	Temperature Gradient	Smoke Behavior (Wind Direction→)
Night—until 1 hr after sunrise. Wind speed is less than 9 kmph (5 knots). Cloud cover less than 30%.	Stable (Inversion) (Ideal)	
Day—most often between 1 to 2 hr before and after sunrise. Wind speed is 9 kmph (5 knots) or more. Cloud cover is 305 or more.	Neutral (Favorable)	
Day—beginning 2 hr after sunrise. Sind speed is less than 9 kmph (5 knots). Cloud cover is less than 30%.	Unstable (Lapse) (Marginal)	

Figure 18. Temperature gradient effects on smoke.

Terrain Effects

Since smoke is carried by the wind, it usually follows the contours of the earth's surface. Therefore, the type of terrain over which the smoke travels has a tremendous impact on how effective the smoke coverage will be in a specified area. Smoke will act differently over the different types of terrain.

Flat, Unbroken Terrain and Over Water

On flat, unbroken terrain, and over water, the individual smoke streamers take longer to spread out

and mix with other streamers. Therefore, the uniform phase will usually develop a greater distance downwind.

Obstructions

Obstructions, such as trees and small buildings, tend to break up smoke streamers. These streamers re-form, cover a much larger area, and eventually create a more uniform screen. This uniform screen develops much quicker and closer to the smoke source than if the terrain were open. A wooded area, which contains an abundance of obstructions, is the most favorable type of terrain for smoke generator operations.

Large Hill Masses and Mountains

Steep hills and mountains tend to split winds. The winds eddy around the hills and mountains as well as over them. Large hill masses and rugged terrain cause strong cross currents. These currents disperse smoke excessively and create holes and unevenness in the smoke screen. In addition, thermally induced slope winds occur throughout the day and night. These conditions make it extremely difficult to establish and maintain a smoke screen. Wind currents, eddies, and turbulence in mountainous terrain must be continuously studied and observed.

Slopes and Valleys

In areas where there are valleys and other types of slopes, the climatic conditions are usually different at different times of the day. These areas are characterized by thermally induced slope winds that occur throughout the day and night. During the daytime, the heating effect causes these winds to blow up the slope, and they are referred to as up-slope winds. At night, the cooling effect causes the winds to blow down the slopes, and they are called down-slope winds. This is a very general rule; however, it is one which needs to be kept in mind when planning smoke operations.

Table 33. Evaluating conditions for smoke employment.

Factor	Unfavorable	Moderately Favorable	Favorable
Wind	More Than 10 knots	Less Than 10 Knots	5 to 10 Knots
Atmospheric Stability Category	Unstable (Lapse) (Favorable for Smoke Curtain)	Neutral	Stable (Inversion) (Unfavorable for Smoke Curtain)
Humidity	Low	Moderate	High
Precipitation	None	Light Rain	Mist/Fog
Cloud Cover	None	Scattered	Overcast, Low Ceiling
Terrain	Even	Gently Rolling	Complex Topography
Vegetation	Sparse or None (Desert)	Medium Dense	Heavily Wooded or Jungle
Time of Day	Late Morning thru Late Afternoon	Midmorning	1 Hour Before EENT to 4 Hours After BMNT

BMNT—beginning morning nautical twilight
EENT—ending evening nautical twilight

Appendix G

Obscurants and How They Work

Obscurants are particles suspended in the air that block or attenuate a portion (or portions) of the electromagnetic spectrum. The six types of obscurants are natural obscurants (such as fog); by-product obscurants (such as dust); visual smoke (such as WP); and bispectral multispectral and special obscurants. This appendix describes the general characteristics of obscurants, how they work, and what obscurants the United States has in its inventory.

Characteristics

Obscuration occurs when there is a decreased level of energy available for the function of seekers, trackers, vision enhancement devices, or the human eye. Battlefield visibility can be practically defined as the distance at which a potential target can be seen and identified against any background. Reduction of visibility on a battlefield by any cause reduces the amount of smoke needed to obscure a target or objective.

Obscuration generally is not associated with combat power because it is not a lethal tool on the battlefield. However, the deliberate use of smoke and the inadvertent or planned use of dust and/or adverse weather conditions on the battlefield have always been of value to units in the field.

In general, smokes are composed of many small particles suspended in the air. These particles scatter and absorb (attenuate) different spectra of electromagnetic radiation. This absorption reduces transmittance of that radiation through the smoke. When the density (concentration) of smoke material between the observer or EO device and an object exceeds a certain minimum threshold value (Cl), the object is considered effectively obscured.

Smoke, placed between a target and viewer, degrades the effectiveness of that viewer by interfering with the reflected electromagnetic radiations. The amount of smoke required to defeat that viewer is highly dependent upon meteorological conditions, terrain relief, available natural light, visibility, and the absorption effect of natural particles in the atmosphere. Other factors include smoke from battlefield fires and dust raised from maneuvering vehicles and weapon fire.

The ability to detect and identify a target concealed by such a smoke cloud is a function of target-to-background contrast. Smoke clouds reduce target-to-background contrast, making the target more difficult to detect.

The effectiveness of obscuration depends primarily upon characteristics such as the number, size, and color of the smoke particles. In the visible range, dark or black smoke absorbs a large proportion of the electromagnetic waves striking individual smoke particles. Dining bright sunlight you need a higher concentration of black smoke to effectively obscure a target because black smoke particles are nonscattering. At night or in limited visibility, considerably less black smoke is needed.

Grayish or white smoke obscures in the visible range by reflecting or scattering light, producing a glare. During bright sunlight you need a lower concentration than with black smoke to effectively obscure a target. At night or in limited visibility, considerably more than black smoke is needed.

Years of experience with white smoke technology have shown it to be superior to black smoke for most applications. Available white smoke producers include WP and RP compounds, HC, and fog oil (SGF2). WP, RP, and HC are hydrocopic (that is, they absorb water from the atmosphere). This increases particle diameters and makes them more efficient in scattering light. Fog oils are nonhydroscopic and depend upon vaporization techniques to produce extremely small diameter droplets that absorb and scatter light.

Smoke produced by a smoke generator unit or from a series of smoke pots has four distinct phases: streamer, build-up, uniform, and terminal (see Figure 19, on the next page).

Streamer phase is the smoke cloud formed by a single smoke device before it begins to blend with the smoke from other sources.

Build-up phase is the stage of smoke cloud production when individual streamers begin to merge.

Uniform phase is a uniform smoke cloud that occurs after individual smoke streamers have merged. This is the phase commanders want over the target area.

Terminal phase is the stage of a smoke cloud in which the smoke has dispersed and concealment is no longer effective.

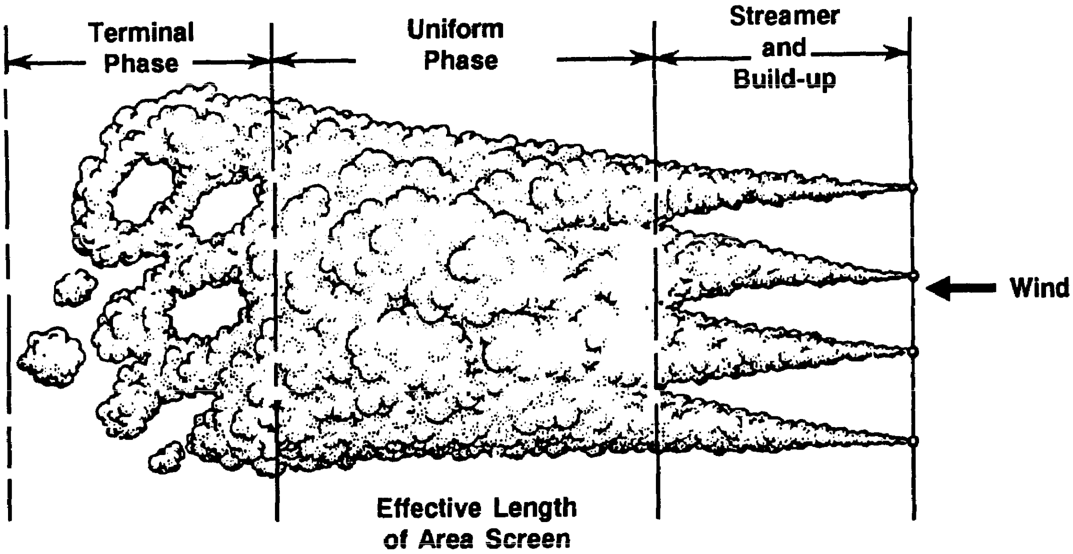

Figure 19. Phases of large-area smoke cloud.

The diffusion of smoke particles into the atmosphere just above the earth's surface obeys physical laws. Wind speed, turbulence, atmospheric stability, and terrain all govern diffusion of smoke. Smoke diffusion on the battlefield originates from four basic smoke source configurations:

- Continuous point sources (such as smoke release from a smoke generator or smoke pot).
- Instantaneous point sources (such as bursting of a WP projectile).
- Continuous line sources (such as a series of smoke generators set up crosswind).
- .Area sources (such as munitions that scatter smoke-generating submunitions like the armored vehicle smoke grenade launchers).

Natural Obscurants

Natural obscurants are produced by nature and are therefore no drain on our assets. However, they are uncontrollable and may aid the enemy as much as friendly forces. We can use natural obscurants to our advantage if we accurately predict the weather and if there is a firm understanding of the impact of that weather on the battlefield. Natural obscurants will create large recognition and identfication problems. Examples of natural obscurants are darkness, fog, sandstorms, and precipitation.

Darkness

Darkness is the most common form of obscuration found on the battlefield. Darkness will degrade visual observation and target-acquisition devices that are not equipped with active infrared, image intensification, or thermal imaging. Systems equipped with these devices can operate at near-normal efficiency during periods of reduced visibility or darkness.

Fog

Fog can be an effective form of obscuration for use on the battlefield. Fog has the capability of providing a good obscurant on the battlefield because it will attenuate visual and near infrared signals in the same manner as visual smoke. Ice fog can also be a very effective obscurant because it degrades systems that operate by the use of a longer wavelength such as thermal imagers. Fog also degrades laser range finders and target designators.

Sandstorms

Sandstorms are encountered in arid and semiarid regions and can have a dramatic effect on military operations. These storms will usually effectively obscure all observation and target acquisition devices with the possible exception of ground surveillance radars and other related devices operating in the microwave region of the electromag netic spectrum.

Precipitation

Precipitation can definitely obscure battlefield viewers depending on the concentration. Rain, mist, sleet, or snow will degrade battlefield visibility greatly. When these elements are present in heavy concentration, there is no need to produce smoke. These elements can reduce visibility by themselves. The use of image intensfiers, active infrared systems, thermal imagers, laser range finders, and ground surveillance radars can be degraded and possibly defeated when the concentration of precipitation is heavy.

By-Product Obscurants

By-product obscurants that produce concealment are a result of other activities associated with battlefield operations. They are often inadvertent; however, when understood, they may be planned and used to the advantage of friendly forces. Examples of by-product obscurants are smoke from burning vehicles and buildings and dust caused by vehicular movement and artillery/mortar fire.

By-Product Smoke

Smoke produced by fire on the battlefield will obscure viewers. This fire can be man-made or naturally produced by elements such as lightning. Other methods of generating fires that may result from a man-made device are fires produced by mortar or artillery rounds. Whether naturally produced or man-made, this obscurant will decrease visibility on the battlefield.

Dust

Battlefield dust is like the proverbial two-edged sword: its presence and use can cut both ways. For example: dust can be used for —

- Concealing details of military forces and movement. Dust is often an indicator of movement of troops and equipment. If the amount of dust generated is large (perhaps deliberately so), details of troop movement can be obscured. If no dust is desired, a simple expedient is to keep the road wet, which can be done if sufficient equipment and ample water are available.
- Blinding enemy observation points to deprive him of the opportunity to adjust fire. Artillery volleys or naval salvos can be used to temporarily obscure a narrow field of view for a short period of time. HE dust clouds are generally only effective as obscurants for several seconds but may be effective up to a minute or more.
- Degrading performance of precision-guided munitions and EO sensors. HE dust can be used to interfere with the target acquisition sequence or to break "lock-on" of an acquired target.

Dust, depending on how it is produced, can obscure different portions of the electromagnetic spectrum, in either the visible, infrared millimeter wave, or radar portions. Dust is often produced inadvertently by bombing, gunfire, and vehicular movement. However, we can plan and use dust to the advantage of friendly forces. Dust degrades the performance of sensors and precision-guided munitions.

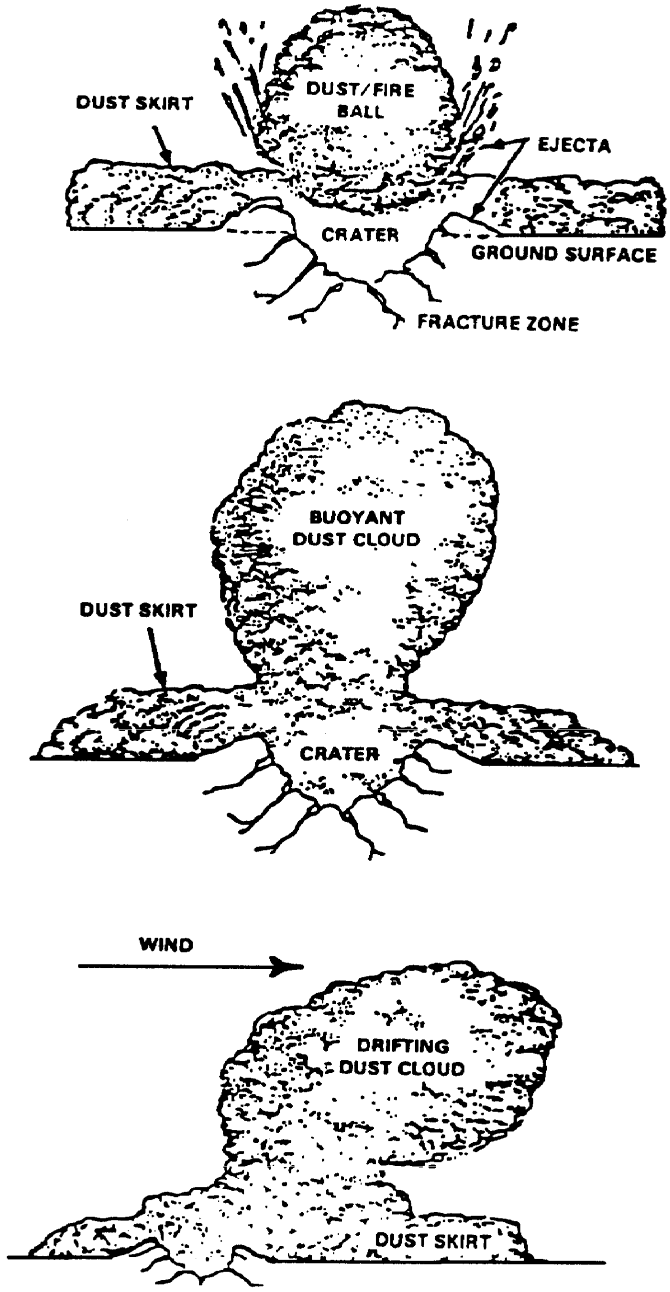

Figure 20. Phases of munition-produced dust cloud.

Munition-Produced Dust

When HE munitions are used, dust will be produced. The amount produced depends on the size of the munition, its point of detonation (above or below the surface), and the state of the soil. The initial explosion throws up a variety of crater materials. From small clumps down to individual soil particles, obscuration will occur at all frequency bands of the electromagnetic spectrum (assuming the explosion is on or near the line of sight). Obscuration times are generally 3 to 10 seconds in the millimeter wave portion of the spectrum; this is the amount of time required for the small clumps and large particles to fall back to the ground. The remaining airborne dust that forms the drifting dust cloud continues to provide obscuration in the visible and infrared portions of the spectrum.

As a rule of thumb for drier soils, dust generally has less effect on IR sensors than on visual sensors such as the eye. For moist or very sandy soils, the two sensors are often affected equally, and under some conditions the IR sensors are obscured more than the visual sensors. In general, infrared sensors will usually offer some advantage over visible-radiation sensors when looking through dust.

Figure 20, at left, shows the phases of a munition dust cloud. The initial phase lasts only a few seconds and quickly blends into the rise phase that lasts about 10 seconds or less. The degree and time of obscuration depend on the dust cloud drift and dissipation phase of the dust cloud with respect to the line of sight and the weather conditions. Dust clouds created by HE have three successive phases: impact, rise, and drill and dissipation.

- Impact phase. Upon munition impact, two parts of a dust cloud are created instantaneously. One part is the hot dust or fire ball, which has an initial size of 4 to 6 meters and is close to the surface. The dust or fire ball is initially several hundred degrees hotter than its surroundings. Most of the dirt and dust are contained in this initial dust or fireball. The second part is the dust skirt, which has a greater horizontal extent of 6 to 10 meters high, and has nearly the same temperature as its surroundings.
- Rise phase. The initial dust or fireball begins to rise and expand, cooling as it rises. The dust cloud top may reach heights of 10 to 30 meters in less than 10 seconds. The dust skirt does not rise but will continue to diffuse outward.
- Drift and dissipation phase. The entire dust cloud, both the buoyant part and the nonbuoyant dust skirt, begin to drift. Wind causes the upper portion to move out ahead while the lower dust skirt lags behind. As the dust cloud drifts, it diffuses, becoming thinner and gradually dissipating.

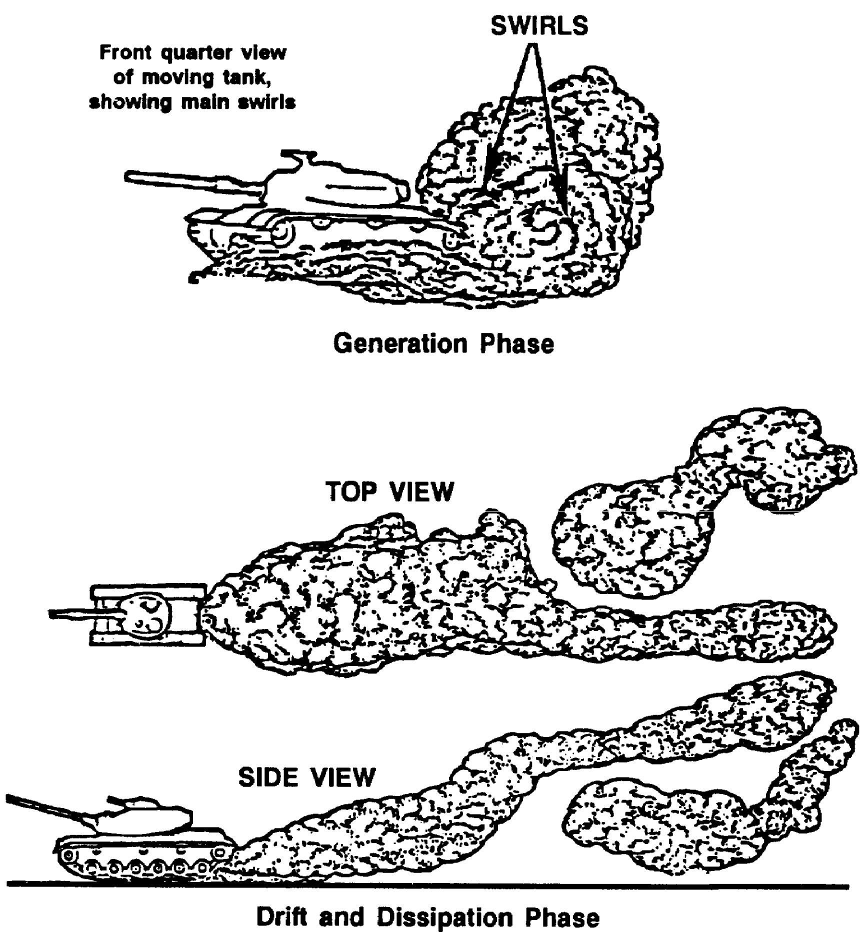

Figure 21. Vehicular dust cloud generation phase and drift and dissipation phase

Vehicular Dust

The amount of dust produced by vehicular traffic depends on the weight of the vehicle, the number of wheels (or tread area), the speed of the vehicle, and the state of the soil. Because vehicles kick up the smaller particles present on the soil surface, vehicular dust does not effectively attenuate the radar or the millimeter wave portions of the spectrum. However, vehicular dust clouds can provide effective obscuration in the visible and infrared portions of the spectrum. Vehicular dust can be divided into two phases: generation and drift and dissipation (Figure 21).

- Generation phase. In this phase, the dust is thrown up or lifted off the surface by the vehicle's wheels

or treads and is swept up in the turbulent air under and behind the vehicle. The total amount of dust produced increases with the speed of the vehicle.

• Drift and dissipation phase. After the dust has been swept up behind the vehicle, it begins to drift and diffuse with the wind. As before, the degree and duration of obscuration depend on the position of the dust trail with respect to a line of sight and the weather conditions.

Artificial Obscurants

We cannot control the behavior of natural and by-product obscurants with the degree of certainty required to defeat enemy RSTA efforts. While natrual and by-product obscurants block or attenuate portions of the electromagnetic spectrum, we must produce obscurants artificially to attack enemy electro-optical systems. We classify US obscurants as visual, bispectral, multispectral, and special..

While 98 percent of all current batelfield viewers operate in the visual portion of the spectrum, future systems will acquire and engage, using IR and millimeter wave technologies. This will require integration of each class of US obscurant to attack and defeat these systems. The following portions of this appendix describe the militarily significant, artificially producted obscurants.

Visual Smoke

Many years of experience with smoke technology has shown white smoke to be superior to black smoke for most applications. Currently we have no black smoke production agents, although the US Navy does have black smoke production capability. The three principle agents for producing white smoke are oils (SGF2 and diesel), HC, and phosphorous.

Oil Smoke

We make oil smoke by vaporizing fuel oils in mechanical smoke generators or engine exhausts. The generator or engine exhaust vaporizes either SGF2 or diesel fuel and forces into the air where it condenses into a dense white smoke. This smoke can produce effective obscuration of the visual through near-infrared portions of the electromagnetic spectrum.

Hexachloroethane Smoke

HC is a pyrotechnic composition of hexachloroethane, zinc oxide, and aluminum powder. A pyrotechnic starter mixture usually ignites the burning reaction. The smoke produced is zinc chloride during burning. This zinc chloride reacts with the moisture in the air to form a zinc chloride solution in tiny droplets: smoke. When first produced, HC smoke is very hot but cools rapidly and has little tendency thereafter to rise. HC munitions generally have definite burn times, which are useful for planning purposes.

Phosphorous Smoke

Caution

HC is carcinogenic. Soldiers must wear respiratory protection (for example, a protective mask) while in HC smoke.

Phosphorus is a flammable solid that burns to form solid particles of phosphorous pentoxide in the air: smoke. The phosphorous pentoxide then reacts with moisture in the air to form phosphoric acid. We use phosphorous smokes in instantaneous-burst munitions (for example, artillery and rifle grenades), with the showers of burning phosphorous particles being highly incendiary. This makes phosphorous smoke excellent for harassing enemy personnel and starting fires, as well as its having excellent smoke properties.

Phosphorous smoke burns so hot that it tends to form a pillar of smoke, which rises rapidly. While this pillaring reduces the efficiency of phosphorous smoke, the by-product of the heat is that it obscures from the visual through the far-infrared portions of the electromagnetic spectrum. The three phosphorous smokes are WP, PWP, and RP.

Caution

Phosphorous smoke produces phosphoric acid. Soldiers must wear respiratory protection, such as protective masks, if exposed to phosphorous smoke.

WP is a spontaneously flammable natural element. It ignites on contact with air and is relatively unstable in storage. WP burns at 5,000 degrees Fahrenheit, making it the most effective smoke agent to defeat thermal imagery systems.

PWP is a formulation of white phosphorus and some other agents (for example, butyl rubber) to stabilize the smoke agent fill and slow the burning. This slowed burning tends to produce a more coherent smoke cloud with less pillaring.

RP is not spontaneously flammable, requiring ignition to burn and make smoke. RP burns at a lower temperature – 4,000 degrees Fahrenheit – which produces a

more coherent smoke cloud with less pillaring. It is less incendiary than either WP or PWP, making it safer for use in smaller cartridges (for example, 40-millimeter grenades). Some munitions such as the M825 155-millimeter howitzer cartridge use felt wedges saturated with RP to produce an even distribution of smoke agent around the point of burst.

Bispectral Obscurants

Bispectral obscurants defeat or degrade two portions of the electromagnetic spectrum simultaneously. As previously stated, phosphorous smokes defeat both the visual and infrared portions of the spectrum. Other bispectral capabilities include type III IR obscurant, which is a micropulverized metal compound. Currently we use this bispectral obscurant in self-defense systems only (for example, the M76 smoke grenade for armored vehicle grenade launchers). In the near term we will have and use a large-area bispectral obscurant capability.

Multispectral Obscurants

AS implied by the name, multispectral obscurants will defeat or degrade multiple portions of the electromagnetic spectrum. Challenges associated with this technology include preventing the inadvertent suppression of friendly force EO systems. In the mid-term we will have and use multispectral obscurants.

Special Obscurants

Special obscurants will defeat specific portions of the electromagnetic spectrum.

Appendix H

PROBABILITY OF DETECTION

PROBABILITY OF DETECTION

AIR STABILITY	WIND SPEED (MPH)	SOURCE STRENGTH (6 GENERATORS)	DOWNWIND DISTANCE (KM)	PROBABILITY OF DETECTION
UNSTABLE	5	5 lbs/min	1	55%
			3	75%
			5	95%
	5	10 lbs/min	1	35%
			3	60%
			5	80%
	10	5 lbs/min	1	85%
			3	100%
			5	100%
	10	10 lbs/min	1	55%
			3	85%
			5	100%

PROBABILITY OF DETECTION

AIR STABILITY	WIND SPEED (MPH)	SOURCE STRENGTH (6 GENERATORS)	DOWNWIND DISTANCE (KM)	PROBABILITY OF DETECTION
NEUTRAL	5	5 lbs/min	1	25%
			3	50%
			5	80%
	5	10 lbs/min	1	15%
			3	40%
			5	55%
	10	5 lbs/min	1	40%
			3	65%
			5	80%
	10	10 lbs/min	1	10%
			3	25%
			5	40%

PROBABILITY OF DETECTION

AIR STABILITY	WIND SPEED (MPH)	SOURCE STRENGTH (6 GENERATORS)	DOWNWIND DISTANCE (KM)	PROBABILITY OF DETECTION
STABLE	5	5 lbs/min	1	0%
			3	5%
			5	10%
	5	10 lbs/min	1	0%
			3	0%
			5	5%
	10	5 lbs/min	1	5%
			3	15%
			5	25%
	10	10 lbs/min	1	0%
			3	5%
			5	5%

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References

New reference material is being published all the time. Present references, as listed below, may become obsolete. To keep up to date, see DA Pam 25-30 (on microfiche).

Required Publications

Required publications are sources users must read to understand or comply with this publication.

Field Manuals (FMs)

3-6, Field Behavior of NBC Agents (Including Smoke and Incendiaries)
100-5, Operations
101-5, Staff Organization and Operations

Related Publications

Related publications are sources of additional information. They are not required to understand this publication.

Army Regulations (ARs)

310-25, Dictionary of United States Army Terms
310-50, Authorized Abbreviations and Brevity Codes

Field Manuals (FMs)

3-100, NBC Operations
3-101, Chemical Staffs and Units
6-20, Fire Support in the AirLand Battle
17-95, Cavalry Operations
25-100, Training the Force
34-1, Intelligence and Electronic Warfare Operations
71-3, Armored and Mechanized Infantry Brigade
71-101, Infantry, Airborne, and Air Assault Division Operations (HTF)
100-2-1, Soviet Army Operations and Tactics
100-2-2, Soviet Army Specialized Warfare and Rear Area Support
100-2-3, The Soviet Army Troops Organization and Equipment
101-5-1, Operational Terms and Symbols

Soldier Training Publications (STPs)

3-54B1-SM, Soldier's Manual, MOS 54B, Chemical Operations Specialist, Skill Level 1
3-54B2-SM, Soldier's Manual, MOS 54B, Chemical Operations Specialist, Skill Level 2
3-54B34-SM-TG, Soldier's Manual, Skill Levels 3/4 and Trainer's Guide, MOS 54B, Chemical Operations Specialist

Glossary

AA – assembly area.

AAR – after action report.

abn — airborne

ACR – armored cavalry regiment.

ACRV – artillery command and reconnaissance vehicle.

aerosol — fine particles of solids or liquid suspended in air.

AD – air defense.

AG – advanced guard.

AICV – armored infantry combat vehicle.

AirLand battle imperatives – key operating requirements for success on the battlefield to ensure unity of effort; anticipate events on the battlefield; concentrate combat power against enemy vulnerabilities; designate, sustain, and shift the main effort; press the effort; move fast, strike hard, and finish rapidly; use terrain, weather, deception, and OPSEC; conserve strength for decisive action; combine arms and sister services to complement and reinforce; understand the effects of battle on soldiers, units, and leaders.

AMC – Army Materiel Command.

APC – armored personnel carrier.

arty – artillery.

ASG – area support group.

ASP – ammunition supply point.

ATGM – antitank guided missile.

attenuate — reduce the effectiveness, amount, or force of.

bispectral obscurant – an obscurant that blocks or attenuates two portions of the electromagnetic spectrum (such as visual and infrared).

blanket – See smoke blanket.

BMNT – beginning morning nautical twilight.

bn – battalion.

BSA – brigade support area.

build-up phase – the second stage of smoke cloud production; occurs when the individual smoke streamers start to merge.

CAS – close air support.

CCA – Combat Command A.

CEOI – Communications-Electronics Operation Instructions.

CEV – combat engineer vehicle.

CFL – coordinated fire line.

CFV – cavalry fighting vehicle.

CLOS – command to line of sight.

CMO – civil military operations.

COSCOM – corps support command.

CP – command post.

CRP – combat reconnaissance patrol.

CRSTA – counterreconnaissance, surveillance, and target acquisition.

CSS – combat service support.

curtain – See smoke curtain.

DAG – division artillery group.

decon – decontamination.

deliberate smoke – characterized by integrated planning; may be used for extended periods for stationary or mobile missions.

det – detachment.

DEW – directed-energy weapon (such as high-energy microwaves, lasers).

DISCOM – division support command.

DPICM – dual-purpose improved conventional munition.

DS – direct support.

DSA – division support area.

EA – engagement area.

EENT – ending evening nautical twilight.

eff — effective.

electro-optical system — a device that detects targets by converting the electromagnetic radiation (visible, infrared, microwave) given off by the target into electric current; this current is amplified, then used to power a viewer or targeting system; this devise can detect targets not visible to the naked eye.

EMP – electromagnetic pulse.

EO – electro-optical.

EW – early warning.

FA – field artillery.

far infrared – electromagnetic energy with wavelengths of 8 to 14 micrometers.

FASCAM – family of scatterable mines.

FDC– fire direction center.

FEBA – forward edge of the battle area.

FFL – free fire line.

flank wind – a wind that blows directly across a line between the

smoke objective and the smoke source.

FLIR – forward looking infrared.

FLOT – forward line of own troops.

fog oil – petroleum compounds of selected molecular weight and composition to facilitate formation of smoke by atomization or combustion; the resultant smoke is white.

FScell - fire support cell.

FSCOORD – fire support coordinator.

FSE – forward security element.

FSO – fire support officer.

g – gram.

gen – generator.

GS – general support.

GSR – ground surveillance radar.

G/VLLD – ground/vehicle laser locator designator.

hasty smoke – characterized by minimal planning; used for short periods to counter enemy action or anticipated enemy action of concern to the commander.

haze – a light concentration of obscuration that restricts accurate enemy observation from the air and ground. This prevents accurate enemy target acquisition, but does not disrupt friendly operations that require limited visibility, such as river crossings. A smoke haze allows limited visibility that reduces the recognition of personnel and equipment from 50 to 150 meters.

HC – a pyrotechnic smoke-producing composition of hexachloroethane, zinc oxide, and aluminum powder employed in certain smoke munitions; has a sharp, acid odor; toxic if released in sufficient quantities in enclosed places; the smoke is cool burning when contrasted to white phosphorus.

HE – high explosive.

HMMWV – high-mobility multipurpose wheeled vehicle.

head wind – wind blowing away from the smoke objective and directly toward the smoke source.

HUMINT – human intelligence.

ICM – improved conventional munition.

IFV – infantry fighting vehicle.

IMINT – imagery intelligence.

individual streamer – the initial phase of a smoke cloud, before the streamers from the point sources merge.

inversion — an increase of air temperature with increase in height (the ground being colder than the surrounding air); this condition usually occurs on clear or partially clear nights and early mornings until about one hour after sunrise, but sometimes persists longer. When stable conditions exist, there are no convection currents and, with wind speeds below 5 knots, little mechanical turbulence. Therefore, stable conditions are the most favorable for ground-released smoke.

IPB – intelligence preparation of the battlefield.

IPE – individual protective equipment.

ir — infrared.

ITV – integrated TOW vehicle.

k – knot(s)

km– kilometer(s).

kmph – kilometer(s) per hour.

LAMPSS – large-area mobile projected smoke system.

lapse – a marked decrease of air temperature with increasing altitude (the ground being warmer than the surrounding air). During unstable or lapse conditions, strong convection currents are found. For smoke operations, the state is defined as unstable. This condition is normally the most unfavorable for the release of smoke.

LC – line of crossing.

LD – line of departure.

LIC – low-intensity conflict.

LOGPAC – logistics package.

LRP – logistics release point.

LTOE – living table of organization and equipment.

m – meter(s).

marking smoke – smoke employed to relay prearranged communications on the battlefield. Frequently used to identify targets, evacuation points, and friendly unit perimeters.

MBA – main battle area.

mech – mechanized.

METT-T – mission, enemy, terrain, troops, and time available.

mid-infrared — electromagnetic energy with wavelength in the range of 3 to 8 micrometers.

min – minute(s).

mm – millimeter(s).

MOGAS – motor gasoline.

MOUT – military operations on urbanized terrain.

MRB – motorized rifle battalion.

MRC – motorized rifle company.

MSR – main supply route.

MTOE – modified table of organization and equipment.

multispectral obscurant — an obscurant that blocks or attenuates more than two portions of the electromagnetic spectrum (such as visual, infrared, and millimeter wave).

NAI – named areas of interest.

NBC – nuclear, biological, and chemical.

NBCC – nuclear, biological, and chemical center.

NCO – noncommissioned officer.

near infrared — electromagnetic energy with wavelengths of 0.7 to 3 micrometers

neutral – a meteorological condition that exists when conditions are intermediate between lapse and inversion; neutral conditions tending toward lapse favor production of smoke curtains; neutral conditions tending toward inversion favor smoke blankets or hazes.

night-vision device — a viewer enabling an operator to see in the dark; also called night-observation device.

NFL – no fire line.

NTC – National Training Center.

OB – order of battle.

obj — objective.

obscurant – chemical agent that decreases the level of energy available for the functions of seekers, trackers, and vision-enhancement devices.

obscuration smoke – smoke placed on or near enemy positions to minimize enemy observation both within and beyond the position area.

oil smoke – see fog oil.

OP – observation point.

OPCON – operational control.

operational continuum – the strategic environment within each theater, consisting of a variety of political, military, and economic conditions and a range of threats that result in a wide range of operations conducted within a continuum; consists of three general states: peacetime competition, conflict, and war.

OPLAN – operation plan.

OPORD – operation order.

OPSEC – operations security.

PD – proximity detonator.

phases of smoke – see individual streamer, build-up phase, uniform phase, and terminal phase.

PHOTINT – photographic intelligence.

PIR – priority intelligence requirement.

PL – phase line.

plt – platoon.

POL – petroleum, oils, and lubricants.

protection smoke – smoke produced to defeat or degrade target acquisition or guidance systems or the effects of directed-energy weapons.

PWP – plasticized white phosphorus.

quartering wind – a wind that blows between tail and flank winds, toward the smoke objective.

RAG – Regimental Artillery Group.

rd – round.

recon — reconnaissance.

red phosphorus – a form of phosphorus not spontaneously flammable.

RFL – restrictive fire line.

RISTA – reconnaissance, intelligence, surveillance, and target acquisition.

RP – red phosphorus.

RPV – remotely piloted vehicle.

RSTA – reconnaissance, surveillance, and target acquisition.

S1 – adjutant.

S2 – intelligence officer.

S3 – operations officer.

S4 – logistics officer.

screening smoke – smoke employed in areas of friendly operation or in areas between friendly and enemy forces to degrade enemy ground and aerial observation; used to conceal ground maneuver, breaching, and recovery operations, as well as key assembly areas, supply routes, and logistic facilities.

selected area – as used in this manual, an area to be concealed by smoke.

SG – smoke generator.

SGF2 – smoke generator fog number 2; also called fog oil.

signature — the visible or audible effects produced when firing a weapon or operating a piece of equipment, such as noise, smoke, flame, heat, or debris; also, an electronic emission subject to detection and traceable to the equipment producing it.

silhouette – the outline or general shape of something contrasted against a lighter background.

SLAR – side-looking airborne radar.

smoke – a particulate of solid or liquid, part of low-vapor pressure that settles out slowly under gravity; in general, smoke particles range downward from about 5 micrometers in diameter to less than 0.1 micrometer in diameter; also means the suspension of small liquid or solid particles in air; the filling for smoke munitions, such as bombs, shells, and grenades; to produce signaling or screening smoke with any munition; generally, any artificial aerosol.

smoke blanket – a dense concentration of smoke established over and around friendly areas to protect them from visual observation from the air and visual precision bombing attack, or established over an enemy area to protect attacking aircraft from air defense fire. Blankets can also be used at night to prevent enemy-observed air attack by flare light, A smoke blanket reduces visual

recognition of personnel and equipment to less than 50 meters.

smoke control officer — the officer designated by the maneuver unit commander to coordinate and control the smoke operation.

smoke curtain – a vertical development of smoke that reduces the enemy's ability to clearly see what is occurring on the other side of the cloud; visual recognition depends on the curtain width and smoke density.

smoke generator – a mechanical device that vaporizes fog oil and releases it to condense in the air as a white smoke.

smoke haze — a light concentration of smoke placed over friendly installations to restrict accurate enemy observation and fire, but not dense enough to hamper friendly operations; density of haze is equivalent to that of light fog.

smoke munition — a device that is either discharged from a weapon or thrown and that makes smoke.

smoke point source — the point from which a smoke munition or smoke device generates an individual streamer of smoke.

smoke position – location of a smoke pot or mechanical smoke generator.

smoke pot – an expendable bucket- or pot-like ammunition that produces a dense smoke by burning a smoke mixture.

smoke projectile – any projectile containing a smoke-producing agent that is released on impact or upon bursting; also called smoke shell.

smoke shell – see smoke projectile.

smoke target analysis — the process of selecting the optimal smoke delivery system to attack specific EO systems.

smoke target development — the process of situation development and intelligence preparations of the battlefield.

SOP – standing operating procedure.

sophisticated weapons — precision-guided munitions, equipped with infrared, electro-optical, or laser seekers/trackers with or without command links; munitions with high accuracy and, hence, high probability of kill against a target.

special smoke — an obscurant that blocks or attenuates a specific portion of the electromagnetic spectrum (such as visual, infrared, and millimeter wave).

spt – support.

sqd – squad.

stable — see inversion.

streamer – the smoke cloud formed by a single smoke source.

synchronization — the coordination of activities in time, space, and purpose to achieve maximum combat power at the decisive point.

TAA – tactical assembly area.

TAACOM – theater Army area command.

TAC – Tactical Air Command.

TAI – target areas of interest.

tail wind – a wind that blows toward the smoke objective from behind the smoke source.

temperature gradient – comparison of the air temperature at .5 meters above the ground with the air temperature at 4 meters above ground; see also inversion, neutral, and lapse.

terminal phase – that stage of a smoke cloud when the cloud has thinned out and the cover is no longer effective; see also smoke blanket.

thermal infrared – electromagnetic energy with a wavelength range of 3 to 20 micrometers.

TOC – tactical operations center.

TOE – table of organization and equipment.

TOW – tube-launched, optically tracked, wire-guided.

TPU – tank and pump unit.

TVA – target value analysis.

uniform phase–phase of smoke during which the uniformly obscuring cloud exists – the streamers have joined and breakup of the cloud has not begun.

unstable — see lapse.

UTM – universal transverse mercater.

VEESS – vehicle engine exhaust smoke system.

visibility – the distance at which it is possible to distinguish a prominent object against the background with the unaided eye.

visibility criteria — the unit commander's requirement for minimum visibility in a smoke cloud. For example, in obstacle emplacement by engineers, the maneuver brigade commander may want to conceal the engineer operation without hindering their work. He establishes a visibility criteria (such as 150 meters) for the smoke.

visible spectrum — the portion of the electromagnetic spectrum lying between 0.4 and 0.7 micrometers.

white phosphorus — a spontaneously flammable solid that burns to form solid smoke particles of phosphorus pentoxide; the phosphorus pentoxide then reacts with moisture in the atmosphere to form droplets of phosphoric acid; the dilution depends on the relative humidity.

WP – white phosphorus.

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By Order of the Secretary of the Army:

CARL E. VUONO
General, United States Army
Chief of Staff

Official:

THOMAS F. SIKORA
Brigadier General, United States Army
The Adjutant General

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MAGELLAN
AEROSPACE

MAGELLAN AEROSPACE ANNOUNCES CONTRACTS TO PRODUCE AIRCRAFT ILLUMINATION FLARES

Toronto, Ontario – 19 December 2023 -- Magellan Aerospace Corporation (“Magellan”) announced today, an agreement with the Canadian government for the provision of LUU-2 illumination flares for the Royal Canadian Air Force (RCAF). The $39 million, four-year contract commences in 2024 and involves the manufacture, assembly, and delivery of LUU-2 flares from Magellan Aerospace, Winnipeg's propellant plant in Manitoba, Canada.

The LUU-2 is an air-deployed high-intensity illumination flare. The RCAF utilizes the LUU-2 to support night time search and rescue operations with illumination. The flares produce about 1.8 million candlepower of visual illumination for five minutes. The LUU-2 flare is a vital resource for the men and women in our armed forces who are called on in times of need or crisis.

Mr. Haydn Martin, Magellan’s Vice President, Business Development, Marketing and Contracts said, “Magellan Aerospace, Winnipeg has been in operation since 1930 and has amassed a legacy of providing military aircraft and critical mission equipment; supporting Canada’s military during times of conflict as well as in times of peace. Magellan appreciates the continued confidence of the Canadian government and takes great pride in delivering mission critical products and services to the Canadian Armed Forces for more than 80 years.”

Second only to the U.S. military, the Canadian Armed Forces is the largest user of LUU-2 flares in the world.

About Magellan Aerospace Corporation

Magellan Aerospace Corporation is a global aerospace company that provides complex assemblies and systems solutions to aircraft and engine manufacturers, and defense and space agencies worldwide. Magellan designs and manufactures aeroengine and aerostructure assemblies and components for aerospace markets, advanced proprietary products for military and space markets, and provides engine and component repair and overhaul services worldwide. Magellan is a public company whose shares trade on the Toronto Stock Exchange (TSX: MAL), with operating units throughout North America, Europe, and India.

Forward Looking Statements

Some of the statements in this press release may be forward-looking statements or statements of future expectations based on currently available information. When used herein, words such as "expect", "anticipate", "estimate", "may", "will", "should", "intend", "believe", and similar expressions, are intended to identify forward-looking statements. Forward-looking statements are based on estimates and assumptions made by the

Corporation in light of its experience and its perception of historical trends, current conditions and expected future developments, as well as other factors that the Corporation believes are appropriate in the circumstances. Many factors could cause the Corporation's actual results, performance or achievements to differ materially from those expressed or implied by the forward-looking statements, including those described in the "Risk Factors" section of the Corporation's Annual Information Form (copies of which filings may be obtained at www.sedar.com). These factors should be considered carefully, and readers should not place undue reliance on the Corporation's forward-looking statements. The Corporation has no intention and undertakes no obligation to update or revise any forward-looking statements, whether as a result of new information, future events or otherwise, except as required by law.

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For information:

Laura Podaima
Director, Corporate Communications
Magellan Aerospace
Ph. +1 204 228 3719
laura.podaima@magellan.aero

ENGINEERING DESIGN HANDBOOK

MILITARY PYROTECHNICS SERIES

PART TWO—SAFETY, PROCEDURES AND GLOSSARY

HEADQUARTERS, U. S. ARMY MATERIEL COMMAND OCTOBER 1963

HEADQUARTERS
UNITED STATES ARMY MATERIEL COMMAND
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31 October 1963

AMCP 706-186, Part Two--Safety, Procedures and Glossary, forming part of the Military Pyrotechnics Series of the Army Materiel Command Engineering Design Handbook Series, is published for the information and guidance of all concerned.

(AMCRD)

FOR THE COMMANDER:

SELWYN D. SMITH, JR.
Major General, USA
Chief of Staff

OFFICIAL:

R.O. Davidson

R. O. DAVIDSON
Colonel, GS
Chief, Administrative Office

DISTRIBUTION:
Special

PREFACE

This handbook constitutes Part Two of a planned series on Military Pyrotechnics and forms part of the Engineering Design Handbook Series of the Army Materiel Command. Part Two deals with the problems of safety in the pyrotechnics laboratory and plant, processing procedures and equipment, particle size procedures, and contains a glossary of terms.

Part Three, a separate handbook with the same date of publication, contains data sheets on 128 ingredients used in pyrotechnic compositions.

Part One, under preparation at the time of publication of Parts Two and Three, will deal with the physical and chemical theoretical aspects of the production of pyrotechnic effects, and the application of the theory to practice. It will also include a history of the pyrotechnic art and an extensive bibliography.

A future volume, currently in the planning stage, will be devoted to discussion of methods used in the evaluation of pyrotechnic items, determination of their compliance with the requirements of the using services, special equipment and procedures which are followed in tests and evaluation, and considerations affecting the interpretation of results.

Material for Parts Two and Three was prepared by McGraw-Hill Book Company for the Engineering Handbook Office of Duke University, prime contractor to the Army Research Office--Durham. The entire project was under the technical guidance of an interservice committee, with representation from the Army Chemical Center, Ballistics Research Laboratories, Frankford Arsenal, Harry Diamond Laboratories, Picatinny Arsenal, U. S. Naval Ammunition Depot (Crane), U. S. Naval Ordnance Laboratory, and U. S. Naval Ordnance Test Station. Chairman of this committee was Mr. Garry Weingarten of Picatinny Arsenal.

Agencies of the Department of Defense, having need for Handbooks, may submit requisitions or official requests directly to Equipment Manual Field Office (7), Letterkenny Army Depot, Chambersburg, Pennsylvania. Contractors should submit such requisitions or requests to their contracting officers.

Comments and suggestions on this handbook are welcome and should be addressed to Army Research Office--Durham, Box CM, Duke Station, Durham, North Carolina 27706.

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CHAPTER 1

SAFETY IN THE PYROTECHNICS LABORATORY AND PLANT

1. INTRODUCTION

This chapter presents the basic principles and considerations involved in achieving safety. It is intended as a guide to help reduce accidents during the research, development, and processing of new and improved military pyrotechnics. The material presented here does not replace existing safety regulations, procedures, Standard Operating Procedures (SOP's) or bulletins, but is intended to supplement them and to aid in the preparation of new regulations.

Safe practices in handling pyrotechnics are the result of the experiences and knowledge of interested personnel and safety experts. All safety-conscious personnel know the necessity for abiding by established safety rules for their own protection and for the protection of others. The processing, testing, storage, and disposal of pyrotechnic materials and items present problems because many of the ingredients and mixtures are toxic, sensitive, and potentially explosive. A thorough knowledge of pyrotechnic ingredients, compositions, and their reactions is an absolute necessity for handling pyrotechnics in the best and safest manner. A bibliography of pertinent literature is included at the end of this chapter. Safety cannot be delegated; it is the responsibility of each worker. Supervisors must personally assume responsibility for educating subordinates and promoting safety within their groups.

Pyrotechnic compositions are physical mixtures of finely powdered compounds and elements. The main constituents are (1) oxidizing agents such as chlorates, perchlorates, nitrates, peroxides, oxides, and chromates; (2) fuels such as powdered metals, silicon, boron, sulfur, hydrides, and sugar; and (3) binders and color intensifiers, which are usually organic. When ignited, these mixtures readily undergo an exothermal reaction that generates considerable energy in a relatively short period of time. The heat of reaction for one gram of pyrotechnic composition ranges from approximately 200 to 2500 calories per gram. This amount of energy, although dangerous, is generally not as destructive as the energy of explosives because it is released as light and heat, with temperatures ranging from approximately 1000° to 3500 °C, rather than as mechanical energy. Loose flash compositions, even when unconfined, are the exception because (1) they release their energy in a much shorter time than pressed pyrotechnic compositions, although less rapidly than explosives; (2) the volume of air entrapped in the composition increases its brisance; and (3) when confined, there is an additional danger from the high velocity fragments of the ruptured case.

Pyrotechnic ingredients and compositions must also be considered hazardous because of their toxicity and sensitivity. Without prior knowledge, or if physico-chemical principles are inadequate, one must consider new ingredients or compositions potentially hazardous. Each new material and composition must be evaluated to determine toxicity, sensitivity, processing hazards, and optimum methods of storage and disposal. Taking chances and failing to follow specified safety practices are the most frequent causes of accidents in the laboratory or plant.

2. BASIC SAFETY RULES

The safety precautions that apply to pyrotechnics may be summarized in the following four rules:

(1) Know the properties of ingredients and the reactions of compositions.

(2) Recognize the dangerous situations that may arise because of potential or actual hazards.

(3) Minimize the hazards by working with small samples, and observing established practices for safety equipment, processing, testing, storing, and disposal.

(4) Observe the practices of good housekeeping.

These rules are interdependent, and inattention to one defeats the objectives of the others. To minimize a hazardous situation the conditions that are or can be dangerous must be recognized; this requires a thorough understanding of the characteristics and properties of pyrotechnic ingredients and the practices and procedures that constitute safe housekeeping.

a. Knowledge of Pyrotechnic Materials

No experiment or mixture preparation should be undertaken without thorough knowledge of the properties of the ingredients to be used and the reaction products that result from testing. The literature should be consulted for toxicity, sensitivity, compatibility, storage, and disposal precautions. Before any experiment or preparation is started, each supervisor should make certain his subordinates comprehend fully, and are using, the best and safest practices.

A knowledge of pyrotechnic materials will depend on understanding the following six important characteristics:

(1) Toxicity

(2) Sensitivity

(3) Reactions with other materials

(4) Safe working limits

(5) Storage characteristics

(6) Disposal precautions

The first four points are discussed immediately below. Storage and disposal are discussed under Processing Pyrotechnic Materials.

(1) Toxicity. If toxicity is defined as the inherent ability of a chemical substance to produce injury once it gains access to the body and hazard, as the likelihood of toxic injury occurring while handling or using a chemical, one can see that a chemical of high toxicity is not necessarily a hazard. Under the usual circumstances of handling or use the likelihood of toxic exposure may not arise; whereas, a chemical of low toxicity may be extremely hazardous if handling provides opportunity for toxic exposure.

A chemical must be considered toxic if it injures tissues or organs so as to prevent them from functioning normally. All possible exposures and effects must be considered. In general, chemical injury results from skin contact, ingestion, and inhalation. The eyes may be injured and vision impaired; skin may be irritated, blistered, or burned in such a manner that a permanent scar may be formed. Swallowing may result in irritation or injury to the digestive tract. Inhalation of toxic dusts, vapors, or smokes may result in irritation or permanent injury to the nasal passages and lungs. The degree of injury from contact varies greatly; it may be slight or serious, and may occur rapidly or may be delayed for days, weeks, or years. To produce injury to internal organs, a toxic substance must enter the blood stream through the lungs, the mouth, or the skin (either percutaneously or through an open break).

Avoidance or prevention of toxic exposures may take forms such as the use of protective clothing and equipment, ventilation of buildings, proper design of equipment, and proper storage of toxic chemicals. Thus, all those concerned (supervisors, safety officers, engineers, and operators) must make a concerted effort to reduce hazards. All personnel handling chemicals should know possible hazards, control, and first aid treatment. The extent of prevention procedures must be determined by the possibility of exposure under the conditions of use, by the toxicity of the chemical, by the nature of its effects in or on the body, and by the way in which it gains access to the body.

The health hazard normally associated with handling pyrotechnic items, aside from skin contact, ingestion, and inhalation of the components during manufacture, is the inhalation of the end products after dissemination. All ingredients used in pyrotechnics should be considered potentially toxic; this also applies to compositions and the products of reaction. All possible precautions should be taken to minimize exposure to dusts and vapors generated during handling and testing.

Each compound must be treated as a potential health hazard until all exposure limits have been established for man, on an acute and chronic basis. Personnel who come in contact with

pyrotechnic materials should use protective clothing, masks, goggles, and skin creams, and practice personal cleanliness to avoid toxic complications. Safety experts and medical authorities should be notified immediately on any question about exposure to toxic materials or any unusual symptoms after exposure. Labels on stored materials should indicate the toxicity of the material and the antidote or treatment if known.

(2) Sensitivity. The sensitivity of a pyrotechnic composition is considered as its response to external stimuli such as heat, impact, friction, moisture, electrostatic discharge, and initiation. In this section these tests are briefly described. A full description of the testing procedure appears in the section on Evaluation Tests. No full scale preparation of a new or experimental mixture should be undertaken without conducting sensitivity tests on small specially prepared samples. Full scale preparation may be attempted only if the results of the sensitivity tests indicate that no definite or potential hazard exists. If an uncertainty exists, the preparation should be scaled up in minimum increments to gain experience before attempting a full scale preparation. It should be noted that sensitivity tests do not always give a definite correlation with actual practice, because the physical conditions involved in laboratory or plant preparations seldom duplicate the controlled conditions in laboratory sensitivity testing. Experience has shown, however, that sensitivity tests are reliable guides for categorizing compositions with respect to sensitivity.

(a) Sensitivity to heat. Because all pyrotechnic compositions are initiated by heat or heat plus shock, one should use some of the common tests to establish or measure the response of an ingredient or a composition when exposed to heat.

Ignition temperature. This is most often done by placing a small quantity of the material in a thin walled metallic container such as a copper blasting cap, and inserting the cap and its contents rapidly into a molten metal bath of known and controlled temperature. This process is repeated at various selected temperatures, and the time from insertion to reaction is noted. The average time for each temperature is plotted against the reciprocal of the absolute temperature. The slope of the line is calculated in the Arrhenius fashion to yield the activation energy of the sample. This value can be taken as a measure of the sensitivity to heat of the sample. /16/

Autoignition temperature. Another test for sensitivity to heat is maintaining the sample at a constant temperature, somewhat below its expected ignition temperature, and noting if a reaction occurs with extended time of exposure. If no reaction occurs in a reasonable time, the test is repeated with a fresh sample at a little higher temperature. The test is continued until a reaction is obtained in a short period of time such as several minutes. The autoignition temperature test can be used as a rapid means to determine whether the composition will react at elevated storage temperatures. /3/

Flash point. When easily decomposed or volatile organic chemicals are used, it is desirable to determine whether the vapors are readily flammable, and the temperature at which they ignite. The temperature at which ignition takes place can be determined by means of the flash point test. If the vapors are found to be ignitible below elevated temperatures, the ingredient should not be used unless means are provided to prevent escape of the flammable vapors. /7/

Vacuum stability. The vacuum stability test subjects the sample, while under vacuum, to a selected elevated temperature for a predetermined period of time. If an excessive amount of gas is evolved the material is considered unstable. /4/

Flammability. The flammability test determines the likelihood that a pyrotechnic charge will catch fire when exposed to an open flame. In this test the sample is exposed to an oxyhydrogen flame at a specified distance for a fixed period of time. The time to reaction is noted. /3/

(b) Sensitivity to impact. Sensitivity to impact is another important safety parameter to personnel who prepare, handle, and transport pyrotechnic compositions. The test procedure most often used is the placing of a small sample of the material on a hardened steel plate and dropping a

known weight from selected heights. Fresh samples are subjected to weight drops of varying heights until no reaction is obtained. This value is taken as a measure of the sensitivity to impact. /4/

(c) Sensitivity to friction. Qualitative tests may be conducted by rubbing a small quantity of the mixture between unglazed porcelain plates or with an unglazed mortar and pestle. Another test is to place a small portion of the sample on a hard surface and strike it a glancing blow with a hammer. /3/ Friction tests are important when determining safety for processing and transporting the mixture.

A more quantitative test employs a pendulum friction device developed by the Bureau of Mines. The apparatus consists of a supported pendulum to the lower end of which is attached a shoe designed for interchangeability of different types of surfaces. The pendulum is adjusted, before testing the sample, to give a specified number of swings across the anvil. The shoe is permitted to fall from a specified height and to sweep back and forth across the sample held in a steel anvil having deep grooves cut into it at right angles to the line of swing. The sample is first subjected to the steel shoe and if a reaction occurs before ten samples have been tested, the test is discontinued and a fibre shoe is substituted for the steel shoe and the testing is continued. /3/

(d) Sensitivity to moisture (hygroscopicity). The hygroscopic nature of the pyrotechnic material or its ability to absorb moisture from the atmosphere must be known if it is to be considered for military application. The rate at which moisture is absorbed and the weight absorbed will depend on such factors as the particle size of the material and its purity, and the ambient relative humidity. An important parameter with respect to the hygroscopic property of a pyrotechnic ingredient is its critical relative humidity. This is the relative humidity value below which the ingredient will not absorb moisture and above which it will absorb moisture. The absorption of moisture by an ingredient can affect the sensitivity to ignition, propagation and stability of a pyrotechnic composition. /3,6/

(e) Sensitivity to electrostatic discharge. To evaluate the ease with which a pyrotechnic ingredient or mixture is initiated by electrostatic energy, one places a small sample of the material in a depression of a steel block. The apparatus is adjusted to give the desired number of joules and the needle point is positioned to permit the discharge of the spark when the critical distance between the needle and sample is reached. Reactions such as burning and sparks are recorded. /6, 12, 15/

(f) Sensitivity to initiation (ignitibility). Although pyrotechnic compositions may be initiated by such stimuli as heat, impact, friction and electrostatic discharges, sensitivity to initiation is usually considered as the minimum energy required to cause complete propagation of the composition. Heat is the usual source for this energy and may be accompanied with hot gases or hot solid particles.

There is no established method for determining the ignitibility of pyrotechnic compositions. For special applications varying amounts of igniter compositions have been used, as well as miner's cord at varying distances. Compositions have also been subjected to the flash from varying amounts of black powder to obtain an indication of the sensitivity to initiation.

(3) Reactions With Other Materials (Compatibility). Compatibility, which is the ability of an ingredient or composition to remain unaffected when in contact with other ingredients or a container, is an important parameter with respect to sensitivity and storage characteristics. Many combinations of ingredients such as potassium chlorate and red phosphorus are very dangerous, and some ingredients will react with the container material. Table 1-1 lists a number of chemical combinations of common materials that are known to be incompatible. It is especially important that all tools and equipment that come in contact with either ingredients or compositions be meticulously clean because unclean tools may affect the performance and stability of a pyrotechnic composition.

(4) Safe Working Limits. During development of a new item, tests should be conducted to determine the consequences of accidental initiation.

TABLE 1-1. HAZARDS OF PYROTECHNIC INGREDIENTS

All items are assumed to be comparatively finely divided, and some of the metals and nonmetals are in the form of dust. Oxidation products that are substantially inert are not included. Degree of hazard may be increased by decreased particle size and increased temperature, and may be affected by presence of moisture or air. Impurities may alter sensitivity to reaction.

FUELS

Inorganic (metals, alloys, and nonmetals): In the finely divided state react vigorously with oxidizing agents. Easily ignited in air by flame or spark. Many are pyrophoric when very finely divided. Contact with water should be avoided.

Fuel	Hazard
Alkali metals:	React violently with water; possible explosion. Oxidize on exposure to air. React violently when heated with CO_2, halogens, and chlorinated hydrocarbons. Keep under kerosene.
Lithium	Reacts explosively with sulfur. Handle under a blanket of argon or helium gas (not nitrogen).
Potassium	Forms explosive mixtures with chlorinated hydrocarbons. Reacts with nitrates, sulfates, hydroxides, chromates, manganates, silicates. Handle under a blanket of nitrogen gas. Destroy if stored for some time while exposed to air. Small amounts can be disposed by reacting in ethanol. Burn large quantities.
Sodium	Reacts explosively with sulfur; when molten reacts violently with sulfur dioxide. Presents same hazards as potassium.
Alkaline earth metals:	React with moisture and oxidize in air, but much more slowly than alkali metals. Storage under kerosene not necessary.
Calcium	Reacts explosively with hexachlorobenzene or sulfur. Reacts vigorously without explosion when heated with titanium dioxide or tungsten trioxide. When finely divided will burn in oxygen at 300°C. Reacts violently with halogens above 400°C. Reacts with fluorine at room temperature.
Magnesium	Dust clouds explode when heated or ignited by a spark. Reacts with chlorinated hydrocarbons and halogens. Reacts when heated with alkali oxides, hydroxides, and carbonates.
Aluminum	Reacts with water and may ignite because of liberated hydrogen. Dust may explode in air. Reacts violently when heated with carbon tetrachloride and other chlorinated hydrocarbons and carbon dioxide. Reacts with halogens. May explode when heated with hexachlorobenzene or tellurium.
Boron	Dust may explode spontaneously in air or when ignited by a spark.
Carbon Black, Lampblack	May ignite or explode spontaneously in air or when heated by flame or spark. Reacts spontaneously with sulfur and drying oils.

TABLE 1-1. HAZARDS OF PYROTECHNIC INGREDIENTS (Continued)

Fuel	Hazard
Copper	Reacts with hydrogen peroxides and organic chlorides.
Graphite	Substantially inert. Difficult to ignite. When ignited burns with intense heat.
Magnesium-Aluminum Alloy 50/50 and 65/35	Presents much the same hazard as magnesium and aluminum.
Manganese	May ignite in air. Can be ignited by an electric spark.
Molybdenum	Oxidized by moisture at room temperature. May explode when heated in air.
Nickel	May explode when heated in air.
Phosphorus	Reacts when heated with alcohol to form ethylene and spontaneously flammable phosphine. Burns in air or carbon dioxide when heated. Reacts with sulfur when heated.
White or yellow:	Ignites spontaneously in air. Reacts with organic materials. Store under water and keep below 44°C.
Red:	May ignite spontaneously in air if it contains sufficient yellow phosphorus. Reacts with organic materials. Mixture with chlorates are extremely sensitive.
Silicon	Reacts with steam at red heat. Reacts with the halogens.
Sulfur	May react explosively in air. May ignite spontaneously in the presence of carbon, lampblack, fats, oils and other organic materials. Reacts violently when heated with mercuric oxide. Reacts explosively when ground together with metallic sodium and with the alkali metals and zinc when heated. Reacts violently when heated with potassium oxide. When heated with ammonium nitrate, the mixture ignites.
Titanium	Explodes spontaneously in air; reaction more vigorous if small amount of water is present. Burns when heated in CO_2 or nitrogen. Reacts when heated with carbon tetrachloride. Pyrophoric when very finely divided. Keep wet with at least 25% water of water plus alcohol. Handle only in inert atmosphere of argon or helium.
Tungsten	May explode when heated in air.
Zinc	May explode when heated in air. Reacts violently when heated with strong alkalies. Reacts when heated with CO_2 or CCl_4. Reacts explosively with sulfur.

TABLE 1-1. HAZARDS OF PYROTECHNIC INGREDIENTS (Continued)

Fuel	Hazard
Zirconium	Reacts when heated with water vapor, oxygen, nitrogen, carbon monoxide and dioxide, halogens, sulfur, carbon, silicon, phosphorus, boron, and aluminum. Fires difficult to extinguish. Pyrophoric when very finely divided. Keep wet with at least 25% water. Handle only in an inert atmosphere of argon or helium.
Zirconium-Nickel Alloy 70/30, 30/70	Less reactive than either nickel or zirconium.

Inorganic Compounds: Not usually hazardous by themselves. Vary in ease of decomposition by heat and reactivity with oxidizing agents.

Fuel	Hazard
Antimony Sulphide	Reacts with hot water and steam. Decomposes on heating.
Calcium Phosphide	Reacts with water and spontaneously liberates flammable phosphine. May explode when heated by a flame. Liable to spontaneous combustion.
Calcium Silicide	Reacts with water and liberates flammable silicon hydrides. When, heated it decomposes and may burn or explode.
Ferrous Sulfide	Reacts with water.
Zirconium Hydride	Reacts violently on heating with easily reducible oxides. Reacts at red heat with all except the noble gases forming nitride, carbide, oxide, etc. Dry powder can be ignited by a static spark or shock.

Organic Compounds: Combustible; most represent no other particular hazard by themselves. Only a few are used as fuels, although many organic ingredients are used as additives. May react with oxidant present but their reaction as a fuel is secondary.

Fuel	Hazard
Anthracene	Heated vapors may explode when ignited in air. Reacts when heated with oxidizing agents, particularly strongly with CrO_3.
Dextrin	No particular hazard.
Lactose	Reacts vigorously when heated with oxidizing agents, expecially chlorates. Dust can be ignited in air by an electric spark.
Sugar	Reacts when heated with oxidizing agents, particularly chlorates.

OXIDANTS

Inorganic Compounds: Form sensitive mixtures with powdered metals and organic materials. The sensitivity and reactivity are increased as the temperature is raised, and may result in explosion. Avoid exposure to water vapor as many oxidants are hygroscopic. The sensitivity of mixtures containing the following oxidizers decreases in the following order (approx.): chlorates, perchlorates, peroxides and some oxides, nitrates, chromates. These classes and their individual compounds are listed below in alphabetical order.

Chlorates

Barium Chlorate	Reacts when heated with finely divided metals, ammonium salts, sulfur, sulfides, phosphorus, finely divided organic materials, oils, greases, charcoal and solvents.

TABLE 1-1. HAZARDS OF PYROTECHNIC INGREDIENTS (Continued)

Oxidant	Hazard
Potassium Chlorate	Sensitive to shock or heat and when mixed with reducing materials such as sugar, charcoal, shellac, starch, sawdust, oils and grease, lint, vegetable dusts, alcohols and other organic solvents, powdered metals, ammonium compounds, sulfur, sulfides, and phosphorus.
Chromates	
Barium Chromate Lead Chromate	React vigorously when heated with finely divided metals and easily oxidizable materials.
Nitrates	
Ammonium Nitrate	Reacts vigorously when heated with powdered metals, galvanized iron, lead solder, sulfur, sulfides, phosphorus, chlorides, nitrates, chlorates, nitrites, organic nitro compounds, charcoal and oxidizing carbonaceous material. Ignites when heated with sulfur.
Barium Nitrate	Reacts vigorously when heated with reducing materials, particularly phosphorus, sulfur, and sulfides.
Calcium Nitrate	May be exploded by shock, heat, flame or chemical action. Reacts vigorously when heated with boron, phosphorus, sulfur, sulfides, sodium acetate, and flammable organic materials such as oils, tallow, and fibrous materials.
Lithium Nitrate	May explode when heated with reducing agents, phosphorus, sulfur, and sulfides.
Potassium Nitrate	Can be detonated by shock. Reacts vigorously when heated with boron, phosphorus, sulfur, sulfides, sodium acetate, and flammable organic materials such as oils, tallow, and fibrous materials. Handle as an explosive.
Sodium Nitrate	Dangerous fire and explosion hazard when heated alone or with reducing materials.
Strontium Nitrate	Reacts vigorously when heated with phosphorus, sulfur, sulfides, and reducing materials.
Oxides and Peroxides	
Barium Peroxide	May explode when heated with magnesium, aluminum, zinc, phosphorus, sulfur, sulfides, charcoal, and other reducing materials. Reacts with moisture.
Chromic Acid	Reacts vigorously when heated with most metals, acetic acid, acetone, alcohol, glycerine, flammable and reducing materials.
Cuprous Oxide	Explodes when heated with powdered magnesium.
Ferric Oxide	When heated can act as an oxidizer, e.g., thermite; reaction with aluminum.

TABLE 1-1. HAZARDS OF PYROTECHNIC INGREDIENTS (Continued)

Oxidant	Hazard
Ferrosoferric Oxide	When heated can act as an oxidizer.
Lead Oxide	May explode when heated with magnesium.
Lead Peroxide	When heated reacts with reducing materials and may ignite. Mixtures with red phosphorus, sulphur, sulphides, and charcoal are sensitive to impact and friction. May detonate when heated with powdered aluminum, magnesium, or zinc.
Lead Sesquioxide	When heated with magnesium may detonate.
Lead Tetroxide	When heated reacts with reducing materials. May explode when heated with magnesium.
Manganese Dioxide	Reacts when heated with reducing agents. Forms sensitive mixtures with red phosphorus, sulfur, sulfides and hyposulfides.
Molybdenum Trioxide	When heated reacts with sodium, potassium, magnesium, aluminum and silicon and is itself reduced to the metal. When heated with zinc there is only a partial reduction. Reacts with halogens and molten potassium chlorate.
Silicon Dioxide	Reacts when heated with metals. May explode when heated with magnesium.
Strontium Peroxide	May be detonated by heat, shock, or catalysts. Reacts violently when heated with reducing materials, magnesium, aluminum and zinc. Mixtures with red phosphorus, sulfur and sulfides are sensitive to impact, friction and heat. Reacts with water.
Zinc Oxide	Hydrolyzes slowly in water. May explode when heated with powdered magnesium.
Perchlorates	
Ammonium Perchlorate Barium Perchlorate Calcium Perchlorate Lithium Perchlorate Potassium Perchlorate Strontium Perchlorate	Behave very similarly. When heated may ignite and explode. When heated with powdered metals, particularly magnesium and aluminum, sulfur, sulfides, phosphorus, and combustible carbonaceous material, react violently.
Polychlorotrifluoroethylene	Comparatively inert. Under conditions of high shear, where fine particles of fresh metal are exposed, soft metals such as aluminum and magnesium react vigorously.

ADDITIVES

This includes a variety of materials, most of which are added in comparatively small proportions to compositions for special purposes such as intensifying color, retarding, binding. The oxidants listed below result from the burning of the compositions. The miscellaneous materials have been grouped below for convenience.

Additive	Hazard
Carbonates and Bicarbonates	
Barium, Calcium, and Magnesium Carbonate; Potassium and Sodium Bicarbonate	React with mineral acids, giving off CO_2. Represent no hazard. Used as coolants or antiacids.
Catalyst (for polymerization)	
Cobalt Naphthenate	Marketed as a 6% solution in mineral spirits. Spirits are volatile and flammable and may explode when heated in air. Explodes on mixing with methylethyl ketone peroxide (see Lupersol DDM under Fuels--Organic).
Color Intensifiers	
Inorganic	
Barium and Strontium Chlorides	Present no particular hazard.
Organic	
Dechlorane	Comparatively inert.
Hexachlorobenzene	Dangerous when heated with alkalies or metals. Explosive chloracetylene is produced.
Hexachloroethane	When heated to decomposition produces toxic fumes of chlorides. Relatively inert.
Polytetrafluoroethylene (Teflon)	When heated reacts with molten alkali metals and fluorene.
Polyvinylchloride	When heated reacts with alkalies.
Dyes	May behave as fuels and react when heated with strong oxidizers.
Explosives	
Black Powder	Detonated by friction, heat, impact, or by electric spark.
Nitrocellulose	When dry extremely sensitive to shock and friction. Easily accumulates static charges. Highly inflammable and explosive. Decomposition on storage is accelerated by acids and alkalies, resulting in possible fire or explosion.
Tetranitrocarbazole	May explode on heating.
Oxalates	
Barium, Calcium, and Strontium Oxalate	Give off dangerous CO.
Oxides	These result from the burning of compositions containing the corresponding metal or metal compound.
Alkali Oxides Potassium and Sodium Oxides	React with water with the evolution of heat, which in the presence of organic material may be sufficient to cause ignition.
Alkaline-earth Oxides, Calcium, Barium, and Magnesium Oxide	

TABLE 1-1. HAZARDS OF PYROTECHNIC INGREDIENTS (Continued)

Additive	Hazard
Aluminum Oxide	Reacts vehemently when heated with calcium carbide.
Chromic Oxide	When heated decomposes suddenly at 330°C.
Potassium Oxide	Reacts violently when heated with sulfur.
Titanium Dioxide	Reacts vigorously when heated with metallic calcium.
Solvents	
Acetone	Vapors form an explosive mixture with air. Reacts vigorously with oxidizing agents, particularly chlorates, peroxides, and chromic acid.
Alcohol	Vapors form an explosive mixture with air. Reacts vigorously with oxidizing agents, particularly chlorates, chromic acid and sodium peroxide. Reacts with phosphorus at 215°C forming ethylene and spontaneously flammable phosphine.
Carbon Tetrachloride	Reacts slowly with water forming hydrochlorine acid. Reacts when heated with alkali and alkaline earth metals, peroxides, and metal powders such as aluminum, iron, and sodium peroxides.
Dibutylphthalate	Flammable. When heated reacts with oxidizing agents.
Kerosene	Vapors may explode when heated in air. Reacts when heated with halogens and oxidizing agents such as CrO_3, Na_2O_2.
Binders	
Asphaltum	Dust cloud may explode in air.
Calcium Resinate	When heated reacts with oxidizing agents.
Calcium Stearate	No particular hazard. Acts as a retardant.
Castor Oil	Reacts when heated with oxidants, particularly chlorates.
Ethycellulose	Reacts on heating with oxidizers. Dust may be ignited by an electric spark.
Gum Arabic	No particular hazard.
Gum Tragacanth	No particular hazard.
Laminac 4116	The original mixture contains such small amounts of unstable peroxides (e.g., methylethyl ketone peroxide, benzoyl peroxide) that the mixture may be considered merely as combustible.
Linseed Oil	Reacts when heated with sulfur or oxidizing agents, particularly chlorates.
Parlon	Will ignite in the flame of a Bunsen burner, but the flame is self extinguishing. Gives off HCl on heating to decomposition.

TABLE 1-1. HAZARDS OF PYROTECHNIC INGREDIENTS (Continued)

Additive	Hazard	Additive	Hazard
Shellac	Dust can be ignited by an electric spark. Reacts when heated with oxidizing agents, particularly chlorates.	Thiokol Liquid Polymer LP-2	The monomer is polymerized by various organic peroxides. Conventional paint driers and PbO_2 are also excellent.
Stearic Acid	No particular hazard.	Zinc Stearate	No particular hazard.

These tests should be conducted on full scale items, when possible, and should test exposure to heat, vibration, jolt, transportation, drop, and so on. The results of these tests can be used to establish safe limits for processing, testing, storage, and disposal.

b. Recognizing and Minimizing Hazardous Situations

Areas in which actual or potential hazards exist should be noted whenever a new item is being developed or an old item is being improved. Every effort should be made to comply with existing regulations on processing, testing, storage, and disposal. As always, good housekeeping should be emphasized and followed.

Safety experts and other experienced personnel should be consulted to help anticipate trouble spots and minimize potential hazards. Supervisory personnel should always be alert to sensitive areas, and must, in turn, teach subordinates to take all essential precautions.

3. PROCESSING PYROTECHNIC MATERIALS

Many possibilities for accidents exist when processing pyrotechnic ingredients and compositions. Potential hazards must be eliminated in each of the following steps that make up the processing procedure.

(1) Transportation

(2) Storage

(3) Grinding

(4) Weighing

(5) Blending

(6) Granulating

(7) Loading

(8) Drying

(9) Assembly

(10) Testing

(11) Disposal

Also, the following basic principles should be applied to each of the above steps.

(a) Adopt a systematic plan for each experiment or operation.

(b) Work with minimum quantities.

(c) Ground all containers and equipment to avoid electrostatic buildup.

(d) Clean thoroughly all containers, tools, and equipment prior to use.

(e) Conduct work in rooms conditioned to 45-55% relative humidity or when ambient humidity is within these limits.

(f) Check all tools for irregularities, and repair or replace as necessary.

(g) Maintain good housekeeping.

(h) Perform as many operations as possible by remote control.

(i) Eliminate unnecessary dusting.

(j) Wear approved safety clothing, and use only approved equipment.

(k) Store completed blends in airtight and moistureproof containers.

(1) Transportation. When moving ingredients and compositions from one location to another, the material should be in airtight, moistureproof, and unbreakable containers. Sensitive compositions should be transported on a cart, not carried.

(2) Storage. Pyrotechnic compositions should be stored in accordance with prescribed regulations. Storage magazines should not be overloaded and ingredients that may react spontaneously if accidently brought in contact with each other should not be stored in the same magazine or chamber. Each magazine should be clearly marked for firefighting purposes.

Containers should have labels, protected by a clear tape, to indicate contents. It is good practice to indicate on the label the type of hazard associated with the materials. Screw cap bottles should not be used for friction sensitive materials.

(3) Grinding. Pyrotechnic materials must often be reduced in particle size to meet granulation requirements. Depending on the type of material, the granulation desired, and the amount to be ground, one may use ball mills, hammer mills, or other types of pulverizers. Before beginning grinding, the machine should be checked for electrical grounding, cleanliness, and working order, and the material should be screened to remove all foreign matter. The material should be ground in small batches, with precautions taken to reduce the dust hazard. All grinding or pulverizing should be performed in remotely controlled rooms that are equipped to eliminate dust. The rooms should be entered only when the operations have been completed, and then a dust respirator should be worn. When grinding heat sensitive materials such as waxes and resins, dry ice or liquid nitrogen can be used to keep the material solid enough to be pulverized. After grinding, one should rescreen materials to remove any foreign materials that may have been introduced during the grinding process.

(4) Weighing. To avoid accidents that may be caused by electrostatic discharges, all weighing must be carefully done on a clean, electrically grounded balance placed on a table whose top is also electrically grounded. The ingredients should be scooped, not poured, from the container and carefully placed in the balance pan. Separate facilities or balances must be used in weighing oxidants and fuels. Explosives should be weighed only behind safety shields. When weighing is completed, the balances should be thoroughly cleaned and all dust traces removed.

(5) Blending. Blending is one of the most hazardous operations, therefore mandatory procedures must be strictly followed, because pyrotechnic compositions vary widely in sensitivity and stability. When preparing an experimental mixture for the first time, one should prepare quantities no larger than 50 grams, then test for sensitivity to impact, friction, heat, and electrostatic discharge. If the composition proves sensitive to one or more of the above characteristics, consideration should be given to selecting another composition or working with the largest quantity consistent with safety and the advice of safety experts. Consideration should also be given to preparing the mixture with a nonflammable volatile liquid, which can later be removed by drying. Wet blending is generally considered safer than dry blending and is used when a mixture is known to be sensitive. When using a liquid for mixing, adequate ventilation must be provided to remove the fumes.

(6) Granulating. After blending, some pyrotechnic compositions are granulated to make them free flowing and easier to handle during pressing. As with other machines, the granulator must be electrically grounded, clean, and in proper working order before the start of operations. If the composition being granulated contains a volatile ingredient there must be adequate ventilation and provisions made to remove it.

(7) Loading. The loading of a pyrotechnic item is most commonly done by consolidating the charge by a press or by vibrating the loose powder into the item. Before beginning any loading operation, the sensitivity characteristics of the composition must be known. Only approved machinery in proper working order should be used. Strict adherence to standard operating procedures and the use of prescribed safety equipment is mandatory. The loading operation should be conducted with barricaded and well-grounded equipment that can be operated remotely.

Except for some loose smoke and flash compositions, pyrotechnic materials are generally pressed into bullets or into cylindrical paper, plastic, or metal cases, in the form of candles. The candles burn progressively from one end to the other -- "cigarette-type" burning.

Because of the pressure used in a pressing operation, friction is the greatest hazard. Every precaution must be taken to avoid friction between moving parts of the press and loading tools. Constant inspection is required to keep the press and tools deburred, aligned, and meticulously clean.

Operating procedures should not only describe the method of operating the press and general safety precautions, but also prescribe what to do in case of any irregularity in the functioning of the machine. For example, if an excessive temperature rise is noted in any part of the press, the press should be shut down immediately; if a

shaft or any part should freeze on a bearing surface, no attempt should be made to loosen the part by force until all ignitible material is removed from the area; if any oil leak develops the press should be repaired before continuing; if the mixture is contaminated or suspected of being contaminated it should be disposed of.

Keeping the press meticulously clean cannot be overemphasized. Should any of the composition get between the ram and the side of the mold, binding may occur, a hazardous condition. Should binding occur no attempt should be made to remove the ram manually. This operation should be done remotely behind barricades by means of a press. The ram should be extracted slowly to avoid heating the composition. Precautions should be taken to prevent injury to personnel and damage to property in the event of an accidental initiation. Thus, it is extremely important that all parts in contact with the mixture be cleaned before each pressing.

If the composition is considered unsafe to load by pressing, or if extreme consolidation pressures are not required, the composition may be compacted by vibration. This procedure should be carried out by remote control with all precautions taken to reduce the amount of dusting. The optimum vibration frequency and amplitude depend on the size, weight, and shape of the container, and the flow properties of the powder. All equipment and the operating area should be carefully cleaned after completion of the loading operation.

(8) Drying. When a composition has been prepared with the use of a carrier liquid, it should be thoroughly dried before loading. The major part of the liquid should be removed by air drying in a ventilated room, with the remaining liquid removed by drying in an explosion-proof, temperature-controlled oven. Provisions must be made to remove the vapor as released. The safe drying temperature of the composition must be known before placing it in the heated oven.

(9) Assembly. When pyrotechnic devices are assembled, controlled operations are desirable. The temperature and humidity should be carefully controlled and dusting of the composition should be kept at a minimum. The least practical number of completely assembled items should be kept in a work area.

(10) Testing. The completed item must be tested in accordance with local or standard regulations. Equipment should be checked for working order and electrical grounding. Barricades should be used if a detonation may occur. If an item fails to function, no attempt should be made to determine the nature of the malfunction until sufficient time has elapsed to assure that the item is not reacting. The "dud" should be handled cautiously, preferably by remote control, and disposed of as soon as possible. Care should be taken to avoid inhaling the reaction products of burning compositions because many of these are toxic.

(11) Disposal. Safe disposal of pyrotechnic ingredients and materials is a problem because of the flammable, explosive, or toxic nature of many of these. Occasionally, small quantities of acids, alkalies, and acetones can be simply disposed of down the drain, provided abundant cold water is used. But even completely water-soluble solvents such as acetone and ethanol must be diluted with large volumes of water to avoid flammable vapors that may become a fire hazard in the drain. Also, there is always the possibility of chemical action between different materials occurring in the drain. Another drawback to this disposal practice is the damage that corrosive chemicals such as acids may have on the drain pipes, and the hazard to personnel who service or otherwise maintain the drainage system.

To minimize the above problems, it is necessary to segregate wastes, with the ultimate disposal carried out in strict accordance with the local operating procedures for each laboratory or plant. Particular care must be exercised to prevent placing materials that might react with each other in the same container. Special waste containers should be used to segregate the waste materials, and the containers must be clearly labeled as to their contents.

Most laboratories and plants specify the maximum amount of waste that may be safely stored. This limit must never be exceeded. Keeping below this limit requires regular, planned trips to the waste disposal area.

The waste disposal area should be located far enough from the laboratory or plant so that any fire, smoke, or fumes produced will not be objectionable or hazardous to personnel. The area should be fenced and posted so that it is clearly recognizable as an area specifically and exclusively reserved for disposing of chemicals.

When disposal of extremely hazardous compositions is being conducted, the handling should be followed step-by-step from the time they are placed in disposal containers until their ultimate disposal. Only then can supervisory or safety personnel be assured that all workers are adequately protected from hazard.

4. ELECTRICAL HAZARDS

The increasing use of electrical equipment and flammable materials in the laboratory and plant adds to the possibility of accidents. The electrical installation must preclude accidental ignition of flammable liquids, vapors, and dust released to the atmosphere. This necessitates the use of explosion-proof lighting fixtures, nonarcing and nonsparking switches, circuit breakers, motor starters, receptacles, and so on. All electrical machinery must be equipped with explosion-proof motors, and must be firmly connected to an approved electrical ground. Portable lamps and flashlights must be of the approved type because fatal explosions have been caused in dust-filled rooms by the arc from the switch of an ordinary flashlight.

Besides the hazards presented by electrical equipment, the hazards associated with static electricity are always present. Proper safety precautions such as wearing conductive shoes, the minimum use of outer woolen and silk clothing, and the electrical grounding of laboratory tools and utensils, and conductive floors and working surfaces both properly grounded must be observed faithfully. In many cases personnel performing the operation must also be electrically grounded to insure safety.

5. FAILURE OF SERVICES

An electrical power failure, loss of cooling water, or loss of almost any other service such as telephone presents a potentially hazardous situation. This is particularly true when working with reactive chemicals. In anticipation of the loss of services, procedures should be developed to reduce the hazardous situation in as short a time as possible.

6. SAFETY EQUIPMENT

So far, this chapter has discussed safety mainly with respect to ingredients, compositions, and processing. Another point of utmost importance is personal safety equipment. The following items are typical of such equipment:

(1) Flameproof coveralls, gloves, coats, blankets

(2) Protective eye devices

(3) Face shields

(4) Sweat bands

(5) Foot guards

(6) Safety conducting shoes

(7) Industrial gas masks

(8) Chemical cartridge respirators

(9) Dust respirators

(10) Pyrotechnic cream

(11) Soap

(12) Towels

(13) Nonsparking tools

(14) Safety showers

Ordnance Safety Manual, AMCP 706-224 specifies that these devices must be used wherever necessary. The Standard Operating Procedures at each laboratory or plant specify when and how the safety equipment should be used. All laboratory personnel should be thoroughly trained in the use of protective equipment. The correct safety equipment for a particular operation should be selected by the supervisor in charge of the operation before any work is begun.

Soap is an important safety device that is frequently overlooked. The importance of personal cleanliness must be stressed. Frequently washing the hands and face greatly reduces the dangers of inflammation or poisoning when working with toxic materials. The importance of thoroughly washing the hands before eating is obvious.

7. FIREFIGHTING

Proper protection against fires in the laboratory or plant stems mainly from good housekeeping, and observing proper precautions in carrying out work. Personnel should be instructed in the special hazards of materials being handled. The Ordnance Safety Manual and local regulations give procedures that must be followed in the event of fire. Personnel should not approach or attempt to fight a fire while wearing clothing contaminated with pyrotechnic materials or explosives. In the event of a fire, all operations in the building stop immediately and all personnel prepare to assist the fire department. Laboratory and plant personnel must know the location of the nearest fire alarm and firefighting equipment, and must be thoroughly familiar with the use of the equipment. Improper firefighting techniques, such as the use of water on burning compositions, can increase the hazard of a laboratory or plant fire. It must be remembered, however, that the best firefighting equipment available cannot prevent fires; that is the job of laboratory and plant personnel.

8. CLASSIFICATION OF PYROTECHNICS

The only general classification of pyrotechnic ingredients and compositions is found in Army Ordnance Safety Manual AMCP 706-224, where materials are categorized for quantity storage safety distances but not for laboratory and plant use. Individual facilities may establish safety categories but there exists no general systematic scheme for laboratory or plant. Table 1-2 gives the safety classification that appears in the Ordnance Safety Manual. /2/

9. CONCLUSION

Safety is the responsibility of all laboratory and plant personnel. Each supervisor must be responsible for the education of personnel under him and must promote safety by example. The supervisor must assure himself that everything is being done to avoid injury to personnel and damage to property. The introduction of new ingredients requires constant evaluation of safety practices to avoid potential hazards to personnel. New requirements and work on new items call for a program of education to supply new safety information and to develop new skills. Sheets should be prepared for each composition giving detailed information on the sensitivity and toxicity, and special instructions concerning the preparation of the composition. Any accidents should be thoroughly investigated for causes, and then steps taken to remove these causes to avoid similar future accidents.

10. REFERENCES

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TABLE 1-2. SAFETY CLASSIFICATION OF PYROTECHNIC INGREDIENTS, FORMULATIONS, AND END ITEMS

CLASS 1

Aluminum powder (packed and stored in original shipping containers or equivalent)
Charge, spotting, AP, practice M8
Chlorates (packed and stored in original shipping containers or equivalent)
Firing devices
Fuse lighters
Fuse, safety
Magnesium powder (packed and stored in original shipping containers or equivalent)
Mines, AP, practice, T34
Nitrates, inorganic (packed and stored in original shipping containers or equivalent)
Perchlorates (packed and stored in original shipping containers or equivalent)
Peroxides (except high strength hydrogen peroxide, packed and stored in original shipping containers or equivalent)
Squibs, commercial
Thermite
Zirconium (types I and II, spec FED-1655, packed and stored in original shipping containers or equivalent)

CLASS 2

Bomb, photoflash, M122, w/o burster
Chemical ammunition, groups C and D when not assembled with explosive components
Grenades, illuminating
Military pyrotechnics (exclusive of class 4 and 9 items)
  Flares
  Illuminants
  Incendiary ammunition including projectiles, bombs, and grenades exclusive of HE-I rounds
  Igniters and tracer units (for ammunition)
  Signals, including signal lights, smoke signals, and obscuring smoke
Projectiles, illuminating, when not assembled with explosive components
Pyrotechnic materials (exclusive of class 9 and 10 items) when not packed or stored in original shipping containers or equivalent, such as:
  Chlorates
  Illuminating, flare, or signal compositions which have been consolidated in the final press operations
  Perchlorates
  Peroxides
  Powdered metals (including zirconium, types I and II spec FED-1655)
  Thermite and other similar incendiary compositions
Spotting charges (cartridges for miniature practice bombs)

CLASS 3

Grenades, practice, with spotting charge
Mines, practice, with spotting charge or fuze (except Mine, AP, practice, T34)
Simulator, M116

CLASS 4

Bombs, chemical loaded, with explosive burster
Cartridge, HE, colored marker
Cartridges, illuminating
Mines, antipersonnel (bounding type)

CLASS 8

Blasting caps
Detonators (except concussion type, M1)
Percussion elements
Primers, electric (for small arms and 20-mm ammunition)
Primers, percussion (small arms ammunition)

CLASS 9

EC blank powder
Tetrazine, TNR, lead styphnate, and lead azide primer compositions
Black powder
Double base propellant with web thickness less than 0.0075 in., regardless of NG content
Double base propellant containing more than 20% NG
Tracer, igniter, incendiary illuminating, flare, and first fire compositions up to and including final consolidation
PETN, TNT, and small-arms primers not packed in accordance with approved Ordnance Corps drawings or specifications, and not packed for commercial transportation
Tetryl, RDX
MOX-2B
Quickmatch

CLASS 10

Class 4 items, when not packed and stored in accordance with Ordnance drawings
Bomb, photoflash
Cartridge, photoflash
Simulator, M115
Mines, antipersonnel

1. PROCESSING

This chapter presents the basic principles involved in processing pyrotechnic compositions. Because of the wide variety of ingredients and compositions handled by research and development and operating personnel, general procedures, rather than specific directives, are given. A composition is processed only after its safe working limits are determined. To assure the optimum performance, every phase of processing should be carefully controlled. Supervisors should prepare Standard Operating Procedures (SOP's) for each composition, point out any unusual hazards, and indicate necessary precautions. All personnel should be thoroughly familiar with the safety measures discussed in Chapter 1, Safety in the Pyrotechnics Laboratory and Plant.

a. Transportation

Pyrotechnic ingredients and compositions should be transported in their original containers whenever possible. Materials from which samples are to be removed should be preblended for uniformity, then placed in clean, dry containers that will not contaminate the contents. Containers should be hermetically sealed and labeled to conform to local regulations for internal transportation and ICC regulations for off-facility shipment.

b. Storage

(1) Facilities. Storage facilities will differ depending on type, quantity, and size of material under development or manufacture, but they should always be consistent with best safety practice. They should be conveniently located, adequate in size, well lighted, and fireproof. Type and quantity of stored material should be clearly marked on all containers. Fuels and oxidizers should be stored separately. Also, explosives, fuzes, primacord, pyrowire, and associated items should be separated. The smallest quantity of ingredients or compositions, and the smallest number of loaded components necessary to operations should be on hand. Each item should be stored in the recommended type of container under the recommended conditions.

(2) Safety Regulations. Ordnance Safety Manual AMCP 706-224 covers class of fire and explosive hazard, quantity and distance tables, acceptable construction, and barriers for large scale plant operations for the following storage conditions:

1. General storage of bulk chemicals
2. Limited bulk storage of chemicals adjacent to or near composition mixing and blending operations
3. Bulk storage of processed compositions
4. Limited bulk storage of processed compositions adjacent to or near filling and loading operations
5. Bulk storage of loaded components of end items
6. Bulk storage of end items
7. Storage of selected samples prior to evaluation testing
8. Storage under accelerated or long term environmental test conditions
9. Storage of scrap prior to disposal
10. Storage of materials under liquid

AMCP 706-224 should be consulted as a first step toward making a decision about storage of an unfamiliar ingredient or composition. If safety manuals and local regulations do not give explicit storage instructions for a new item, the supervisor, local safety representatives, or other experts should be consulted. Also, every laboratory and plant should have a continuing safety program that includes periodic inventory of samples, ingredients, and compositions to keep the overall quantity of materials to the minimum required to operate efficiently.

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(3) Storage Under Liquid. Ingredients such as white phosphorus are commonly stored under water or a water-alcohol mixture to prevent combustion. The water-alcohol mixture prevents freezing under uncontrolled temperature storage conditions. Removing frozen materials from containers is especially hazardous because of possible friction and impact. Finely divided metals such as zirconium and certain explosives are also stored under water to avoid ignition by friction or static spark discharge from containers.

Special care should be taken when handling finely divided metals that have been stored under liquid. If they are ignited while damp, an oxidation-reduction reaction occurs that can produce a hydrogen explosion. Also, after long standing under water they may settle to the bottom of the container in a tight compact mass. Spatulas or tools should not be used to break up this mass; instead, a stream of water should be directed against it or, if sufficient water covers the mass, the container cover or lid may be replaced tightly and the whole container shaken by remote control or placed on a ball mill until the contents are converted to a slurry. Containers should be inspected periodically for leaks or corrosion.

c. Grinding.

Size reduction techniques for pyrotechnic ingredients are similar to those used in propellant and explosive operations. The same safety precautions apply because many oxidants undergo explosive decomposition, and fuels form explosive mixtures with air. It is preferable to procure ingredients in the particle size required, but if this is not possible, facilities for size reduction should be established.

Grinding equipment for pyrotechnic items must be properly designed, maintained, and periodically inspected for electrical grounding, clearance of moving parts, lubrication, and seals. Seals, especially, may require frequent opening, cleaning, and repacking because of accumulation of ground material. Corrosion-resistant construction should be considered when grinding oxidants inasmuch as water is used to remove the oxidants. Remote control should be designed into all grinding equipment and, if possible, grinders should be charged and material removed without the operator present in the same room.

Friability, hardness, hygroscopicity, and moisture of the material, as well as the size required, will all affect grinding operations. Types of size reduction equipment commonly used in pyrotechnics are described below.

(1) Ball Mills. Ball mills, which are used for wet grinding and fine particle size reduction, vary depending on the size and design of the mill and balls, type of ball material and wear, properties of material being ground, and the weight of the wet or dry charge. One type of ball mill has a 4.5 in. inside diameter and a hemispherical end, against which a stainless steel or aluminum ball rests. The ball, from 2 to 4 in. in diameter, is selected so that the unit force at point of tangency is not excessive for the sample of material. The ball rolls over the particle, without exceeding a maximum force, until it is crushed. The mill is emptied remotely by tipping below the horizontal, the ball is caught on a screen, and the milled product is washed through the screen.

Pebble mills with nonmetallic liners, or ceramic or granite jars are used where metallic contamination must be avoided. Grinding of heat sensitive ingredients is often done with liquid nitrogen as the wetting agent and coolant. The mortar and pestle may be used for size reduction but extreme caution should be exercised when grinding energetic materials.

(2) Pulverizers. Although pulverizers may vary in screen size, mill size and diameter, and rate of feed, the following general considerations usually apply.

Prior to grinding, the material should be screened for lumps and foreign material and, if moist, oven dried. Receiving containers and the chute bag should also be dried. The pulverizer should be checked for proper operation, and electrical equipment and containers should be inspected. The grinding operation should be monitored remotely; checking speed of feed, screen rate, current load on mill, feed motors, and temperature of mill. The mill should be up

to speed before starting the feed and should be stopped only after the feed has been stopped and the mill emptied. The receivers should be removed only when the mill has stopped. For greater control of particle size fractions, cyclonic separation may be used for particle size classification (see below).

d. Classification

Classification is the process of obtaining specific size fractions of finely divided powders by means of sieves or screens, elutriation by air or liquid, sedimentation, centrifuging, or by cyclone classifiers. Sieving is used for particles coarser than 44 microns, and may be done wet or dry. The other methods are for particles in the subsieve range using dry powder. Chapter 3, Particle Size Procedures, covers in detail the classification of pyrotechnic ingredients.

e. Weighing

The performance of a composition depends primarily on the accuracy with which the ingredients have been weighed. Although other unit operations affect the performance of a formulation, they cannot overcome a weighing error.

The size and type of balance used depends on the quantity and volume of material, and the accuracy desired. Laboratory trip balances are used for small quantities; and platform scales, for larger amounts. Balances and scales should be cleaned and checked before each use and readjusted if necessary.

Prior to weighing, ingredients should be dried and screened to remove extraneous materials and lumps. Oxidants and metals should be weighed separately on electrically grounded balances. To insure safety, dusting and spillage must be avoided. Any material unavoidably spilled should be immediately disposed of. After weighing, the material should be transferred immediately to the blender, or placed in clean, hermetically sealed containers until used.

f. Blending

Blending has a marked effect on the ultimate performance of a composition because in this procedure the ingredients are brought into intimate contact with one another to form a homogenous mixture. Whether blending is wet or dry, it should be checked and controlled by analytical procedures to assure homogeneity. For example, insufficient blending time will result in a nonhomogenous mixture, whereas excessive blending time may also result in nonhomogeneity because of unblending.

Besides blending time, factors such as density, volume, particle size, or specific surface of the ingredients affect the final homogeneity. If density and particle size differ markedly for each ingredient, a volatile solvent or binder may be added during blending to minimize segregation. Suitability of the blender is also important as some blenders are suited for either dry or wet blends, whereas others can be used for both. The final volume of the mixture should be optimum for the capacity of the blender. This amount is best determined by using test batches, and checking the homogeneity of the batches at various blending time intervals.

The blender should be placed in a separate airconditioned room or bay provided with adequate illumination and a fume removal system. An electrical interlock system should be used so that the blender will not operate while the doors are open, or while the operator is in the room. Remote controls should be used for all blending operations, with the operator behind a reinforced wall provided with a shatterproof porthole. A mirror in the room is sometimes needed to permit the operator to watch the blending. The room should have a weak wall and an explosion-proof roof. All electrical components, fixtures, and equipment must be explosion proof and electrically grounded. All these items should be periodically inspected. Prior to each blend, the equipment should be inspected for defects, and the blades and scrapers carefully adjusted for clearances. Regulations regarding explosive and personnel limits and safety accessories must be strictly adhered to.

The most commonly used procedures and equipment for blending, which is usually a batch process, are described below.

(1) Dry Mixes. The blending of powders without a solvent or binder may be performed in a conical blender, twin shell blender, or a ball mill. The conical blender is a large steel globe fitted longitudinally with steel baffles. All the ingredients are added to the tumbler at one time. The mixing action is obtained by the revolution of the blender. As the ingredients are carried around by the baffles they are dropped toward the bottom and intermixed.

The twin shell blender (V-blender) is formed from two cylinders cut at an angle and joined together in a "V." Rotation of the blender provides an intermeshing action of the powdered ingredients when the two cylinders combine their flow. Other devices may be incorporated into the twin shell blender to assure rapid mixing.

A ball mill (see under Grinding) can also be used for dry blending by replacing the metal or ceramic balls, for safety reasons, with rubber stoppers. The optimum weight of charge, stoppers, and blending time for each new composition should be determined by preblending.

(2) Wet Mixes. Compositions that are considered insensitive to impact and friction may be prepared by forcing the mixture of ingredients through a coarse screen by means of a rubber stopper. The process is repeated until visual observation indicates uniformity has been obtained. The blending operation should be done behind a barricade, and the hands and face protected by asbestos gloves and a face shield. Although there are many types of blenders available for use with a solvent or binder, the muller type is most commonly used for pyrotechnic compositions. In this type of mixer, the ingredients are combined by an intensive action simulating the mortar and pestle. Within a circular blending pan is a wide heavy muller wheel(s) which is mounted to be vertically adjustable. Plows or scrapers clean the sides and bottom of the pan and force the composition into the path of the mullers during rotation of the pan or mullers. The mix must not be too fluid or there will not be enough friction to rotate the muller(s), and it must not be too tacky or it will build up in front of the plows. Optimum operating conditions should be determined by pretesting.

The usual blending procedure is to first spread a thin layer of the fuel(s) in the pan. The solvent or binder is added and the blender is operated for about five minutes. The remaining ingredients are then added and operation continued until blending is complete. It may be necessary to stop blending periodically to scrape down the sides and bottom of the pan with sparkproof tools to assure homogeneity. Dry areas should be moistened with solvent before scraping.

When a blend is completed it should be removed by remote control and used immediately to avoid segregation, or placed in a hermetically sealed container and preblended prior to use. If the blend has been made with a volatile solvent it should be dried before use (see below).

g. Granulating

Pyrotechnic compositions prepared without a binder may be difficult to pellet because they lack freeflowing properties. To improve the flow characteristics, and also to reduce the tendency to dusting and segregation, and to control burning rate, a nongranular powder is converted to a granular material of a selected size. A dry powder can be granulated by first adding a binder or solvent for the desired consistency, and then forcing the material through a suitable screen. If a large quantity of material is to be used, the material is then dried, and if necessary, rescreened prior to use. The granulating operation should be conducted remotely, if possible, and when solvents are used provision should be made to remove them rapidly.

h. Loading

After blending, the composition is loaded into a test vehicle or end item. All loading operations should be performed by remote control, with operating personnel behind reinforced protective barricades. For purposes of loading, compositions may be classified as follows:

(1) Illuminants and Smokes. These compositions usually contain a binder, and are loaded by consolidating into a case by a hydraulic press. The case, which will later be placed into an end item, may be paper, plastic, or metal tubing.

With small arms and tracers the composition may be loaded directly into an end item. Consilidation is done by placing the case in a split mold to prevent rupture during the pressing operation. Weighed increments are placed in the case and then consolidated at the pressure and for the time previously determined. The loaded container is removed by opening the split mold. The igniter is often pressed with either the first or last increment, and an inert charge may be used to seal the nonigniting end of the item.

(2) Delay Compositions. These are usually handled in the same manner as illuminants and smokes, except that higher pressures are used except when binders are present. Dies are used to support the delay body.

Factors such as the size of the increment, number of increments, consolidation pressure, rate of application,and dwell time all influence the burning characteristics of the consdidated composition. Other factors are the case material and the use of a coating on the interior of the case to make the composition adhere. Voids between the case and the composition may result in a detonation during burning, and scattering of the composition.

(3) Flash and Spotting Compositions. Flash and spotting compositions, because they usually do not contain a binder, are likely to be more sensitive than compositions containing a binder. To minimize loading hazards the composition is loaded by vibration rather than consolidation. This is accomplished by placing the item to be loaded on a vibrating table and charging the case with the composition through a funnel. Vibration of the funnel may be necessary to make the composition flow. The maximum loaded weight of the composition depends on the geometry of the container, the frequency and amplitude of vibration, and the total time of vibration. The composition must be dry because traces of adsorbed moisture will keep it from flowing freely and will result in a lower weight.

f. Drying

Drying may be considered as the removal of a liquid from a gas, liquid, or solid by natural or forced convection. Usually, drying is accomplished by heating the composition at a temperature slightly lower than the boiling point of the liquid present. The temperature may be raised at the end of the drying period to assure removal of final traces of the liquid. Amount of liquid present, vapor pressure of liquid, particle size of solids, porosity of solid, thickness of layer, temperature of oven, and rate of air flow all affect drying rate.

Chemicals as received at the laboratory or plant often contain moisture that must be removed prior to use in pyrotechnic mixtures. The materials are first screened through a coarse screen to break up lumps and remove any foreign material.

Drying is conducted on individual ingredents as well as compositions prepared with volatile solvents, and often on compositions that have been stored. Equipment used varies but usually consists of steam controlled drying room, steam ovens, forced draft and vacuum ovens, and explosion-proof electric ovens. Materials to be dried are placed in trays with a minimum layer thickness. The moisture content should be checked to control drying time.

Although drying procedures may vary to meet local regulations, or because of the nature of a material, the following precautions usually apply.

1. Install equipment in strict compliance with all electrical codes.

2. Equip ovens with covered heating coils and explosion-proof latches. Use double thermostat controls to prevent overheating due to faulty control.

3. Determine whether remote control operation is necessary.

4. Be sure that drying will not increase sensitivity.

5. Be sure that drying will not create a reactive material with possible decomposition.

6. Take steps to eliminate solvent vapors from area.

7. Never charge ovens with incompatible materials.

8. Avoid leaving sensitive materials in ovens over night.

9. Dry extremely sensitive material in high vacuum ovens at maximum temperature of 60°C.

10. Remove solvents in a steam heated, forced draft oven at 60°C.

j. Assembly

This is the final step in readying a composition for performance evaluation and use. Prior to assembly the item should be checked for weight and dimensional requirements, and composition. The assembly room should be air conditioned to avoid moisture pickup by hygroscopic materials, well lighted and safety approved. Only the minimum amount of assembled and unassembled items should be kept on hand.

After the composition is placed into its container, an ignition device such as primer cord, primer, detonator, or squib is added. It is secured with a moisture-proof seal, and the item is marked for identification. The final step may consist of placing the assembled item into a hermetically sealed can.

2. HANDLING AND STORAGE OF PYROTECHNIC DEVICES

Because completely assembled items are often not tested immediately after assembly but stored for future use, there are several precautions that must be observed. The items should be hermetically sealed or jungle wrapped to avoid moisture pickup. If the items are to be transported, they should be firmly packed in a sturdy box so that they will not be affected by vibration. The storage containers should be clearly marked as to contents, and dated. If it is necessary to withdraw a sample from the box, spacers should be inserted to protect the remaining items.

3. DISPOSAL OF WASTE COMPOSITIONS

The reactive and hazardous nature of pyrotechnic compositions makes their disposal a major problem (see Chapter 1, Safety in the Pyrotechnics Laboratory and Plant). The disposal of unique compositions should be undertaken only after consultation with safety experts. The approved method most commonly used is the saturation of waste compositions with motor or lubricating oil. The oil saturated waste is then burned in an approved location. If an ingredient is present that may react with the oil, some other approved flammable liquid should be used.

1. PARTICLE SIZE

This chapter describes methods and techniques of measuring particle size. Sampling techniques, and the treatment of collected data to make analytical results useful to military pyrotechnics, are also discussed. The references at the end of this chapter provide detailed information on fine particle technology.

a. Importance in Pyrotechnics

The output of a pyrotechnic composition depends on its rate of reaction. The rate, in turn, is related to the specific surface and the quantities of the ingredients in the composition. Because factors such as size, shape, distribution, and surface of the particles affect the properties of the particulate material, they must be accurately determined and controlled. These same factors affect the packing properties of the ingredients with the coarser particles packing less densely than the fine particles. This packing, in turn, affects the weight-volume relationship of the particles.

b. Measurement

There is no one accepted method for precisely defining a particle. It is common practice to describe a particle as having a "diameter". With the exception of truly spherical particles, the term diameter is understood to be statistical. Various methods of measuring particle diameter may yield different values.

The methods used in fine particle technology may be classified into two general groups: direct sizing and counting; and indirect sizing.

Table 3-1 lists the most common methods and techniques and gives their approximate ranges. The accuracy and precision of any analytical procedure depends on working with a representative and adequate sample, in which the particles are completely deagglomerated.

2. DIRECT METHODS

a. Microscopy

The microscopic method is used to measure the spatial extensions of single particles and aggregates. This method is useful as the most direct way of determining the shape, size, count, and extent of aggregates. It is indispensable for preliminary examination of powders and is used as the reference for checking other methods.

Both the optical and the electron microscope are used for making particle size determinations; the optical for particles of 0.2 to 100 microns in diameter, and the electron for particles of 0.001 to 5 microns. The optical microscope can be used for particles as small as 0.1 micron if ultraviolet illumination and focusing mirrors are used. With the ultramicroscope, this limit can be extended to 0.01 micron.

(1) Technical Considerations. The most important technical considerations are (1) obtaining a representative and uniform sample from the original material, and (2) dispersing it uniformly on a slide without the formation of agglomerates. Often, dispersing or deagglomerating agents are used when a wet preparation is made. The preparation of a sample for examination depends on the size of the material, and its optical properties. Particle counting, with optical microscopes, can be done by special graticles (or ocular micrometers), by making photomicrographs of the fields to be counted, or by using microprojection equipment and counting from an image on the screen. The references at the end of this chapter give details for slide preparation, sizing, and counting.

(2) New Adaptations. Among promising newer adaptions of the microscope is electronic scanning, in which a narrow-beam device scans a microscope-magnified image of the sample field and electronically counts and classifies the particles.

TABLE 3-1. PARTICLE SIZING TECHNIQUES AND RANGES

	RANGE (microns)
DIRECT	
1. Microscopy	
a. Visible light	0.2-100
b. Electron beam	0.001-5
2. Coulter Counter	10-1000
INDIRECT	
1. Sieving	44 and up
2. Sedimentation	
a. Liquid	
(1) Pipette	2-50
(2) Hygrometer	2-50
(3) Manometer	2-50
(4) Balance	2-50
(5) Turbidimeter	2-50
(6) Centrifuge	0.05-50
b. Gas or Air	2-150
3. Elutriation	
a. Air	5-50
b. Air and centrifuge	2-50
4. Permeability	1-1000
5. Adsorption	
a. Liquid phase	0.01-5
b. Gas phase	0.01-5
6. Light scattering	0.05-1

Other techniques to improve the accuracy of particle counting use polarized light, phase contrast, and dark field illumination. These techniques require considerable experience, but are useful in the hands of a skilled technician.

Particles that are too small to be measured by the optical microscope can often be measured by the electron microscope. Because all matter is extremely opaque to electrons, the sample for an electron microscope must be mounted on a thin film or membrane. This membrane must be thin enough to be transparent to the electron beam yet tough enough to withstand the beam and support the particles. Various methods has been devised for making such membranes and mounting them for viewing.

(3) Disadvantages. The microscopic method has certain disadvantages. Particle size data obtained often bear little relationship to the physical or chemical behavior of fine particles. Statistical description of the size of a finely divided material becomes increasingly complex as the uniformity of size and shape decreases. Because it is difficult to measure extremely fine particles, the results are biased to a larger average value. Moreover, because the particles are seen predominantly in one dimension, size is determined by assuming a spherical shape. Size determinations are therefore inaccurate for markedly nonspherical shapes such as plates and needles.

When making counts on a sample with a wide distribution, it is often necessary to change the magnification to cover the distribution. This can lead to a recount of previously tallied particles. When working with high power objectives, constant focusing is required to determine edge to edge dimensions.

The following three practical drawbacks should also be noted: it requires more skill than many of the other methods; a relatively long time is needed to prepare samples and make counts; and the equipment is sometimes expensive.

b. Coulter Counter

The Coulter Counter analyzes particle size distributions by particle volume measurement. This instrument determines the number and sizes of particles suspended in an electrically conductive liquid. Its principal advantage over other particle size distribution methods lies in the large number of individual particles that can be scaled and counted during an analysis. Selection of a soluble and conductive electrolyte, however, may pose a problem.

The instrument works in the following manner. A small opening, through which the suspension flows, has an immersed platinum electrode on either side. With concentration adjusted so that the particles pass through this opening substantially one at a time, each particle displaces the electrolyte within the opening for a moment and thereby changes the resistance between the electrodes. This change produces a voltage pulse proportional in magnitude to the volume of the particle and the resultant pulses are displayed on an oscilloscope screen as a series of vertical spikes. Thef spikes serve as a guide for measurement and also as a monitor of instrument performance. The pulses are also fed to a threshold circuit constructed in such a way that only pulses that reach or exceed an adjustable screen-out voltage level are counted. The electrolyte in the aperture forms the principal resistance between the electrodes.

Deviations from a linear volumetric response become appreciable for nearly spherical particles when particle diameter is more than 30% of aperture diameter. This effect is markedly reduced for elongated particles such as fibers, rods, and platelets, as the prevailing streamline flow causes such particles to be aligned chiefly with the aperture axis.

3. INDIRECT METHODS

a. Sieving

When carried out under standardized conditions, sieving is a rapid, accurate, and reproducible method of evaluating the mass distribution of particulate materials. The results obtained depend on the size and shape of a particle and the shape of the sieve opening. Density, porosity, and surface characteristics are relatively unimportant.

(1) Sieve Sizes. The lower limit of classification by sieves or screens is fixed by the finest mesh sieve commercially available, 44 microns. Sieves produced by an electroforming process can be supplied in mesh sizes of 10-40 microns. But the extremely fine size of the mesh openings increases the tendency of the material to plug the openings, thus resulting in either non-passage of material or inaccurate results. Also, these very fine sieves must be carefully cleaned.

Standard sieves are pan shaped, with a wire mesh bottom of definite and uniform openings. Usually, these openings are square, although round, slit, and other shaped openings are available. Stainless steel is the preferred metal because it is chemically inert and easy to clean. Table 3-2 gives the range of sieves and their characteristics.

(2) Procedure. By using a series of stacked sleeves, with the coarsest screen on top and the finest on the bottom, the powdered sample can be classified into a number of fractions. The sample, usually less than 100 grams, is placed on the upper screen and the stack is given an oscillatory and tapping motion by hand or by machine. The sample will distribute itself on the sieves, depending on the size and shape of the particles and the size of the openings in the sieve. A bottom pan collects the material passing through the finest sieve.

The number of sieves used in a determination depends on the information desired. If the amount of material retained and passing through a sieve of a specific size is required, then only one sieve is needed. If a particle size distribution is wanted, however, as many as five sieves may be used. Sieving time is considered sufficient when the amount of material passing through a screen is negligible. The material remaining on the sieves or pan is removed and weighed. The data are usually reported as percentage passing through or retained on a sieve, or as percentage finer than a certain micron size. These data can be plotted on log probability paper to yield the average particle size and distribution.

(3) Sources of Error. One source of error in sieving may be from the fracture of particles, which will bias the distribution toward the finer size. To make sure there is no change in mesh size of sieves in use for a long time, they should be calibrated periodically with materials of known distribution or measured microscopically.

Interparticle forces, electrostatic charges, and relative humidity may affect the separation of particles. If agglomeration becomes a problem, separation may be made by using a relatively volatile liquid that does not dissolve or affect the material being screened. The liquid helps to break up the aggregates and keeps the particles from forming new aggregates. This liquid is removed before weighing.

(4) Comparison With Other Methods. It should be noted that the particle size of material passing through one sieve and retained on another is not the same as the arithmetic or geometric mean of the two sieves. Microscopic measurements of sieved fractions show that the average particle size determined microscopically is usually greater than the sieve values. When values obtained by the air permeability method are compared with the mean value of screened fractions, the air permeability values are considerably lower. The relationship between mean particle size data obtained on screens and data obtained by other means depends on the material being analyzed and the methods being compared.

b. Sedimentation

In place of microscopic measurements, sedimentation or elutriation procedures may be used to determine the average particle size distribution of powdered materials finer than 44 microns. Sedimentation procedures are usually preferred because a larger sample can be used. When analysis is conducted under standard conditions the results are reproducible.

(1) Assumption. Sedimentation procedures are based on the principle that particles settle because of gravitational forces. Because the downward acceleration is counterbalanced by frictional forces, each particle reaches its own terminal velocity. The resultant rate of fall is a function of the diameter and density of the par-

TABLE 3-2. RANGE OF STANDARD SIEVES

TYLER STANDARD SCREEN SCALE SIEVES
The W. S. Tyler Co., Cleveland, Ohio

Meshes per Lineal		Sieve Opening		Wire Diameter	
inch	cm.	inch	mm.	inch	mm.
2.5	0.98	0.312	7.92	0.088	2.24
3	1.18	0.263	6.68	0.070	1.78
3.5	1.38	0.221	5.61	0.065	1.65
4	1.57	0.185	4.70	0.065	1.65
5	1.97	0.156	3.96	0.044	1.12
6	2.36	0.131	3.33	0.036	0.914
7	2.76	0.110	2.79	0.0328	0.833
8	3.15	0.093	2.36	0.032	0.813
9	3.54	0.078	1.98	0.033	0.838
10	3.94	0.065	1.65	0.035	0.889
12	4.72	0.055	1.40	0.028	0.711
14	5.51	0.046	1.17	0.025	0.635
16	6.30	0.0390	0.991	0.0235	0.597
20	7.87	0.0328	0.833	0.0172	0.437
24	9.45	0.0276	0.701	0.0141	0.358
28	11.02	0.0232	0.589	0.0125	0.318
32	12.60	0.0195	0.495	0.0118	0.300
35	13.78	0.0164	0.417	0.0122	0.310
42	16.54	0.0138	0.351	0.0100	0.254
48	18.90	0.0116	0.295	0.0092	0.234
60	23.62	0.0097	0.246	0.0070	0.178
65	25.59	0.0082	0.208	0.0072	0.183
80	31.50	0.0069	0.175	0.0056	0.142
100	39.37	0.0058	0.147	0.0042	0.107
115	45.28	0.0049	0.124	0.0038	0.097
150	59.06	0.0041	0.104	0.0026	0.066
170	66.93	0.0035	0.089	0.0024	0.061
200	78.74	0.0029	0.074	0.0021	0.053
250	98.43	0.0024	0.061	0.0016	0.041
270	106.3	0.0021	0.053	0.0016	0.041
325	128.0	0.0017	0.043	0.0014	0.036

U. S. SIEVE SERIES

U. S. Bu. Standards, Standard Screen Series, 1919

Sieve No.	Meshes per Lineal inch	Meshes per Lineal cm.	Sieve Opening inch	Sieve Opening mm.	Wire Diameter inch	Wire Diameter mm.	% Tolerance in Average Opening	% Tolerance in Maximum Opening	% Tolerance in Wire Diameter
2.5	2.58	1	0.315	8.00	0.073	1.85	1	10	5
3	3.03	1.2	0.265	6.73	0.065	1.65	1	10	5
3.5	3.57	1.4	0.223	5.66	0.057	0.45	1	10	5
4	4.22	1.7	0.187	4.76	0.050	1.27	1	10	5
5	4.98	2	0.157	4.00	0.044	1.12	1	10	5
6	5.81	2.3	0.132	3.36	0.040	1.02	1	10	5
7	6.80	2.7	0.111	2.83	0.036	0.92	1	10	5
8	7.89	3	0.0937	2.38	0.0331	0.84	2	10	5
10	9.21	3.5	0.0787	2.00	0.0299	0.76	2	10	5
12	10.72	4	0.0661	1.68	0.0272	0.69	2	10	5
14	12.58	5	0.0555	1.41	0.0240	0.61	2	10	5
16	14.66	6	0.0469	1.19	0.0213	0.54	2	10	5
18	17.15	7	0.0394	1.00	0.0189	0.48	2	10	5
20	20.16	8	0.0331	0.84	0.0165	0.42	3	25	5
25	23.47	9	0.0280	0.71	0.0146	0.37	3	25	5
30	27.62	11	0.0232	0.59	0.0130	0.33	3	25	5
35	32.15	13	0.0197	0.50	0.0114	0.29	3	25	5
40	38.02	15	0.0165	0.42	0.0098	0.25	3	25	5
45	44.44	18	0.0138	0.35	0.0087	0.22	3	25	5
50	52.36	20	0.0117	0.297	0.0074	0.188	4	40	10
60	61.93	24	0.0098	0.250	0.0064	0.162	4	40	10
70	72.46	29	0.0083	0.210	0.0055	0.140	4	40	10
80	85.47	34	0.0070	0.177	0.0047	0.119	4	40	10
100	101.01	40	0.0059	0.149	0.0040	0.102	4	40	10
120	120.48	47	0.0049	0.125	0.0034	0.086	4	40	10
140	142.86	56	0.0041	0.105	0.0029	0.074	5	60	15
170	166.67	66	0.0035	0.088	0.0025	0.063	5	60	15
200	200	79	0.0029	0.074	0.0021	0.053	5	60	15
230	238.10	93	0.0024	0.062	0.0018	0.046	5	60	15
270	270.26	106	0.0021	0.053	0.0016	0.041	5	60	15
325	323	125	0.0017	0.044	0.0014	0.036	5	60	15

BRITISH STANDARD SCREEN SCALE SIEVES
British Engineering Standards Association

Meshes per Lineal		Sieve Opening		Wire Diameter		Wire Standard Gauge	Tolerance Average Aperture ±%	Approx. Screening Area
inch	cm.	inch	mm.	inch	mm.			
5	1.97	0.1320	3.35	0.068	1.73	15.5	3	44
6	2.36	0.1107	2.81	0.056	1.42	17	3	44
7	2.76	0.0949	2.41	0.048	1.22	18	3	44
8	3.15	0.0810	2.06	0.044	1.12	18.5	3	42
10	3.94	0.0660	1.68	0.034	0.864	20.5	3	44
12	4.72	0.0553	1.40	0.028	0.711	22	3	44
14	5.51	0.0474	1.20	0.024	0.610	23	3	44
16	6.30	0.0395	1.00	0.023	0.584	23.5	3	40
18	7.09	0.0336	0.853	0.022	0.559	24	5	36
22	8.66	0.0275	0.699	0.018	0.457	26	5	36
25	9.84	0.0236	0.599	0.0164	0.417	27	5	35
30	11.81	0.0197	0.500	0.0136	0.345	29	5	35
36	14.17	0.0166	0.422	0.0112	0.284	31.5	5	36

BRITISH STANDARD SCREEN SCALE SIEVES

Meshes per Lineal		Sieve Opening		Wire Diameter		Wire Standard Gauge	Tolerance Average Aperture ±%	Approx. Screening Area
inch	cm.	inch	mm.	inch	mm.			
44	17.32	0.0139	0.353	0.0088	0.224	34.5	5	38
52	20.47	0.0116	0.295	0.0076	0.193	36	6	37
60	23.62	0.0099	0.251	0.0068	0.173	37	6	35
72	28.35	0.0083	0.211	0.0056	0.142	38.5	6	36
85	33.47	0.007	0.178	0.0048	0.122	40	6	35
100	39.37	0.006	0.152	0.004	0.102	42	6	36
120	47.24	0.0049	0.124	0.0034	0.086	43.5	6	35
150	59.06	0.0041	0.104	0.0026	0.066	45.5	8	37
170	66.93	0.0035	0.089	0.0024	0.061	46	8	35
200	78.74	0.003	0.076	0.002	0.051	47	8	36
240	94.49	0.0026	0.066	0.0016	0.041	48	8	38

ticle, and the density and viscosity of the suspending medium. For a spherical particle settling in a viscous medium, the diameter is given by Stokes' Law

$$d = \frac{18 \mu V}{(D_1 - D_2) g}$$

where

d = particle diameter, cm

μ = viscosity of medium, poises

V = velocity of settling, cm/sec

D_1 = density of particle, gm/cc

D_2 = density of medium, gm/cc

g = acceleration of gravity, cm/sec^2

Because particles settle in a specific medium at a velocity proportional to their diameters, the concentration and size distribution in the medium will vary with time. If the concentration and weight of the particles can be obtained as a function of time, a size distribution can be calculated.

Stokes' Law assumes a spherical particle, but because the particles in most powdered materials are not usually spherical in shape, it is customary to define a particle as having an "equivalent" or "Stokes" diameter. This is the diameter assigned to an irregular particle, which is equivalent to a spherical particle of the same density and falling at the same rate in the same medium.

Depending on the density of the granular material, the range of particle sizes considered optimum for sedimentation procedures is usually 2-50 microns. With coarse particles of a high density material the initial reading may occur too rapidly to obtain accurate times, whereas fine materials of low density may settle out so slowly that the evaluation becomes too time-consuming.

(2) Sources of Error. In all sedimentation procedures, one assumes that each particle will fall without interference. These procedures are subject to error because of poor or incomplete dispersion of the particles, reagglomeration of the particles, thermal gradients and turbulence in the suspending medium, too great a particle concentration, or the wall effect.

If the suspending medium is a liquid it must not react with the samples, and it should be sufficiently viscous to avoid turbulence, but not so viscous that the time of fall will be unduly prolonged. Often a small amount of a dispersing agent added to the liquid will aid in dispersion, which can be checked microscopically.

(3) Specific Techniques. Many sedimentation techniques for obtaining particle size data have been developed. Some of these devices are briefly described below.

(a) Divers

A series of small bulbs called divers is used to determine the specific gravity of the suspended sample. The distance the bulb falls in a selected time interval is used to calculate the settling time of a particle falling this distance. Because this method requires a large concentration of particles, agglomeration and particle interference may occur.

(b) Pipette

This widely used technique involves withdrawing a series of samples of a suspension at predetermined time intervals at a single fixed level. Each sample is evaporated to dryness and weighed to determine its concentration. From the results the percentage by weight of a particular range of particle size in the original sample is obtained.

Because a high concentration of sample is needed, problems of agglomeration and interference may arise. Moreover, accurate sampling is made difficult by the effects of variables such as the size of the tube used to withdraw samples and the speed with which the samples are withdrawn.

(c) Hydrometer

As with divers, the specific gravity of the suspension is determined. Samples of fixed volume are withdrawn at selected time intervals. From the specific gravity results are corrected to true readings to give the particle size. Agglomeration and particle interference may become problems.

(d) Manometer

As particles settle out of a suspending medium, the density of the suspension changes. These changes are the basis of this method, in which the settling tube is fitted with a capillary side arm, containing a clear liquid, which serves as an inclined manometer. As the particles settle out, the density of the suspending medium decreases and the meniscus in the manometer recedes. Rate of this recession is used to determine particle size distribution in terms of Stokes' Law.

As with other sedimentation methods, problems of agglomeration and interference arise. Moreover, there is some flow of the clear liquid from the manometer into the sedimentation tube, creating convection currents that interfere with settling.

(e) Sedimentation balance

Another device for making particle size determinations is the sedimentation balance, which continually weighs the accumulation of particles as it settles out of the suspension. An automatic recording device or a lever arm with pointer and scale may be used. From weight versus time graphs, together with known data on rate of fall of particular particle sizes, particle size distribution data can be derived.

Serious disadvantages of this method are: (a) Inaccuracies of measurement arising from the gradual downward movement of the pan as particles accumulate in it (this movement causes convection currents in the suspension medium); (b) the need for a highly concentrated suspension, leading to agglomeration and interference; (c) the slowness of fall of the particles.

Sometimes a gas rather than a liquid is used as the suspending medium. This modification is generally an improvement, because the particles fall more rapidly and a longer sedimentation column can be used. One of the best known instruments of this type is the Sharples Micromerograph, which is described below.

The powder sample is projected into the instrument from the top through a powder feed system and deagglomerator. The particles fall through a settling column made of aluminum tubing. The particles fall at their terminal velocities until stopped by the pan of the servo-electronic balance at the bottom of the column. As the particles accumulate on the balance pan, a slight rotation of the balance beam on its torsion suspension occurs. A sensing device incorporated in the balance applies a signal to the electronic system of the instrument, which in turn applies a current to a restoring force coil on the balance beam. The current required to keep the beam balanced is a continuous measure of the accumulated weight of powder on the balance pan. A chart recorder makes a record of the accumulated weight versus time.

(f) Turbidimeter

The relationship between the turbidity of a fluid and its light-transmitting properties can be used for making particle size determinations. A beam of monochromatic light of known intensity in passed through a fluid in which a powdered sample is suspended, and the amount of scattered light is measured. The measurement is made at a fixed distance below the surface of the fluid and is repeated at predetermined time intervals, to secure data on the turbidity of the fluid at several stages of the settling process.

Although subject to some of the shortcomings of all sedimentation procedures--getting satisfactory dispersion, avoiding agglomeration, and so on--the turbidimeter is a convenient and relatively rapid method that gives reasonably accurate results. Only a small sample of moderate concentration is needed. This in itself minimizes problems of dispersion, interference, and agglomeration.

(g) Centrifuge

To speed up the rate of settling of small particles, centrifugal force is sometimes used. Differences between data obtained by centrifugation and data obtained when the particles are allowed to settle gravitationally have been studied, and the hypothesis has been advanced that when centrifugal force is used, the larger particles give impetus to the smaller ones, thereby distorting the sedimentation data. This effect is particularly important where a wide range of particle sizes is present.

c. Elutriation

Elutriation methods, unlike sedimentation methods where the particle moves in a still medium, use a moving medium.

By means of a vertically moving column of fluid, a powdered sample can be fractionated into several particle size categories. The fluid (usually a gas) is passed through the sample at various velocities and each velocity carries away and separates all particles whose terminal velocity of fall is less than the velocity of the moving air. The sample is constantly agitated to allow air to come in contact with all parts of it.

This method gives only general size distribution data, because size distribution within each fraction is not known. Moreover, at lower air velocities, the air flow is twice as rapid at the center of the tube as near the tube walls and this makes sharp separation impossible. A further limitation on its usefulness is that, for the smaller particles (under 5 microns), it takes too long (8 hours when 10% of the particles are under 5 microns) for separation to be effected. In general, elutriation methods suffer from the same sources of error as sedimentation procedures.

d. Air Permeability

The rate of air flow through a bed of compressed particulate material can be used to determine the specific surface (area per unit weight) of that material. From the specific surface the mean surface particle size can be calculated. When either the desired specific surface or particle size distribution of a powdered material has been determined, the average particle size of this material, as determined by air permeability, can be used for control purposes.

This technique is rapid and reproducible and can be used for a variety of materials. Like other methods the particles are assumed to be spherical or essentially spherical in shape. Particle shapes such as flakes or needles give results that can be misleading.

(1) Procedure. Air is driven, at a fixed pressure, through a closed chamber (or cell) containing the compressed sample. The pressure drop across the cell is measured with a manometer and the rate of flow with a flowmeter.

Using a known weight and height of sample, the average particle size of the sample can be calculated from applicable equations. For determining the diameter of spherical or almost spherical particles, this method agrees well with microscopic measurement. (See Table 3-3.) Also, it is excellent for measuring specific surfaces up to about 10,000 sq cm per gram.

(2) Fisher Sub-sieve Sizer. The most widely used air permeability instrument is the Fisher Sub-sieve Sizer, described below. The practical limits for this apparatus is 2-50 microns.

The instrument uses the principle that a current of air flows more readily through a bed of coarse powder than through an otherwise equal bed of fine powder; i.e., equal in shape of bed and apparent volume. Investigators have standardized the conditions, thereby allowing the particle size to be obtained through the use of the instrument chart without mathematical computation.

The Sub-sieve Sizer is composed of an air pump, an air pressure regulating device, a precision bore sample tube, a standardized double range flowmeter, and a calculator chart. The air pump builds up air pressure to a constant head in the pressure regulator. The air, under this pressure head, is conducted to the packed powder sample contained in the sample tube. The flow of air through this packed bed of powder is measured by a calibrated flowmeter, the level of the fluid indicates directly on the chart the average diameter of the powder particle.

In practical use, the Fisher Sub-sieve Sizer offers a simple, rapid, and fairly reproducible means of determining the average particle size of powdered materials. A source of variation

TABLE 3-3. AGREEMENT OF FISHER SUB-SIEVE SIZER AND MICROSCOPE

	Atomized Aluminum			Potassium Perchlorate		
	Fine	Medium	Coarse	Fine	Medium	Coarse
Fisher Sub-sieve Sizer, average particle size, microns	5.0	14.0	39.0	3.0	11.0	24.0
Microscopic count, géometric mean diameter, microns	4.9	19.0	40.0	1.8	6.6	12.5

that may be encountered lies in obtaining reproducible manual packing of a sample to its minimum porosity in the sample tube. The principal limitation of the Fisher Sub-sieve Sizer is that no information is given on size distribution.

Good agreement between microscopic measurements and Fisher Sub-sieve Sizer determinations has been obtained for powders made up of spherical or almost spherical particles. Table 3-3 gives comparative results obtained for spherical atomized aluminum and irregularly shaped potassium perchlorate powders.

The average particle size value obtained by air permeability is biased to a smaller value because the finer particles present have the larger surface areas per unit weight of material.

The determination of average particle sizes between 100 and 500 microns can be made using a permeability apparatus larger than the Fisher Sub-sieve Sizer. This apparatus, which has been developed at Picatinny Arsenal, uses a sample size of approximately ten times the sample density.

e. Adsorption

The methods described to this point are based on the apparent dimensions and configuration of the particle. The presence of minute pores or crevices in the particle are not usually detected by these methods. When the presence of these irregularities is important they can be detected and measured by adsorption techniques from either the liquid or gas phase. The values obtained by these methods give the total surface available to the adsorbent.

(1) Liquid Phase. Some substances such as dyes and fatty acids in solution are readily adsorbed on the surfaces of powdered materials. An excess of a standardized solution of the adsorbent is added to the dry powder, and the unaffected adsorbent is determined by standard analytical procedures. Determinations are made at several different concentrations and the specific surface calculated from the amount adsorbed and the size of the molecule. This method is somewhat inaccurate because the solvent may also be adsorbed on the particles and interfere with the adsorbent. Another factor which leads to inaccuracies is the lack of precise data on the size of the molecule.

(2) Gas Phase. Gases are also adsorbed on the surface of powders and like the adsorption from the liquid phase can be used to calculate the specific surface and mean surface diameter of a powder. This method is more flexible inasmuch as various gases can be used and a wider range of surface areas can be measured. In principle the method consists of determining the amount of gas in a mono-molecular layer adsorbed on the surface of the powder. Plotting the moles of gas adsorbed per gram of solid against the equilibrium pressure at constant temperature an adsorption isotherm is obtained. From the graph the point on the graph corresponding to a monolayer of gas is determined and used to calculate the surface area of the powder.

f. Light Scattering

The average particle size of a sample can be obtained under certain conditions by measuring the intensity of the light scattered by the parti-

cles when suspended in a liquid. The procedure is often referred to as nephelometry. It is a useful technique for particles too small to measure by an optical microscope.

4. SAMPLING

The results obtained on a sample examined for average particle size, particle size distribution, or specific surface can only be as representative of the original material as the sample represents the original material. Because conclusions are drawn from a study of these samples, and inferences concerning the properties and their effects on the behavior of the powders are made, it is important that the sample studied closely represent the original sample or sample lot. To be adequate, a sample must meet the following requirements:

1. It must be truly representative of the whole bulk of particulate material being examined; i.e., all particle sizes and shapes must be present in the same proportion in the sample as in the material being sampled.

2. It must be of a size suitable for examination and analysis by appropriate techniques for determining particle size and shapes. Subsampling is often necessary to reduce the sample to a usable size.

The sampling technique used depends on the type and amount of material to be analyzed. Samples of material can be obtained by:

1. Tumbling the sample container repeatedly until the enclosed sample is thoroughly mixed.

2. Fractionating the original sample with a riffle sampler.

3. Extracting the amount required for analysis, from the smallest working increment obtained, with a standard laboratory spatula or scoop.

The container is tumbled or rolled for 10 to 15 minutes prior to the actual sampling and allowed to set for at least five minutes to permit any fine dust particles present to settle. A closed sample thief is then inserted straight down into the powder until the tip of the thief reaches the bottom of the container. The thief is opened and twisted to make the powder pour into the sampler. The thief is then closed, so that the powder sample remains in the sampler, and the thief is extracted from the drum. Five or six such samples are taken; one from the center, and four or five from approximately equidistant points around the periphery.

The several samples are poured into a common container where they are reblended by thorough tumbling and, prior to subsequent analysis, resampled by means of the riffle sampler. This sampling technique is the most convenient method of obtaining small (less than 100 grams) representative samples of powdered materials from large, heterogeneous quantities.

Errors in the analysis, other than those introduced by sampling, can result from the fracturing of the particulate material during tumbling and sampling, from reagglomeration, and from the adsorption of moisture.

A master sample should be reserved for future reference and analysis. It should be kept dry and should not be handled too frequently.

5. TREATMENT OF DATA

The data collected from a particle size analysis by count, size, or mass become more meaningful when reduced to disclose the type of distribution, average value, and dispersion. The normal or Gaussian distribution is seldom found in particle size analysis. Distributions are usually skewed with a sharp rise at the fine end of the distribution, followed by a tapering off at the coarse end.

The most common distribution found is the so-called log-probability type. This is treated most conveniently by placing the data on log-probability paper, on which the logarithm of the particle sizes is plotted against the cumulative frequency or weight of particles. If a straight

line results, the distribution is log-normal. The average particle size (geometric mean) is found at the 50% point and the geometric standard deviation or dispersion is calculated from the ratio of the 84.13%/50% or 50%/15.87% values. The geometric standard deviation is useful in measuring the range of distribution, for 68% of all particles will have a size within the range

$$\frac{\text{geometric mean}}{\text{geometric standard deviation}}$$

to (geometric mean) (geometric standard deviation).

Sometimes a log-normal plot does not result in a straight line. The distribution may then be bimodal, or have two peak values. This would be shown on the graph as a sudden change in the slope of the line.

Another useful representation of the size data is the histogram. The percent of the total number is shown as a function of the size by a series of sequential parallelograms. The base of each parallelogram is determined by the selected size limits and the altitude by the percentage of particles falling within the size range. The histogram can be smoothed by drawing a curve through the midpoints of the rectangle tops.

The data may also be plotted as the cumulative frequency versus the micron size. This results in an "S" shaped curve, the slope of which depends on the distribution.

One of the advantages in using the probability graph method is the ease of conversion of particle size by count to particle size by weight or vice versa. If an approximately straight line on log-probability paper is obtained for one of these distributions, then the particle size in the material is distributed log normally. The other distribution will also be distributed log normally, with the same standard deviation, but about a different mean. Thus:

$$\log \text{geometric mean by count} = \log \text{geometric mean by weight} - 6.9 \log^2 \text{geometric standard deviation}$$

Specific procedures for handling particle size data and discussions of average particle size and types of distributions and their evaluation will be found in the references.

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This listing is intended to supplement MIL-STD-444, Military Standard Nomenclature and Definitions in the Ammunition Area. Listing of Ordnance Terms and Abbreviations, prepared by the U.S. Naval Ammunition Depot, Crane, Indiana, and Special Text ST 9-152, Ordnance Technical Terminology, printed by the U.S. Army Ordnance School, Aberdeen Proving Ground, Maryland, have also been consulted. Terms given here are not intended for mandatory use, but are included to help readers of this handbook.

ABSORPTION. The talking up of a gas, light, heat, or liquid by a substance.

ACCELERATION. Change of velocity with respect to time. Dimensions (length/time^2).

ACCELERATOR. A substance added to speed up a chemical reaction.

ACTIVATION ENERGY. The energy difference (E) between an active and a normal molecule, acquired as a result of interchanges occurring in collisions, which allow the molecule to take part in chemical or physical reactions; obtained from Arrhenius type relationships such as that between the log of the specific reaction rate (K) and the reciprocal of the absolute temperature (T), ($K = A^{-E/RT}$), where A is a frequency factor or entropy term, and R is the universal gas constant.

ADDITIVE. Any material added to a mixture to modify some physical or chemical property of that mixture (rate of reaction, consistency, stability, structural strength).

ADIABATIC TEMPERATURE. The temperature attained by a system undergoing a volume or pressure change in which no heat enters or leaves the system.

ADSORPTION. The adhesion in an extremely thin layer of the molecules of gases, of dissolved substances, or of liquids to the surfaces of solid bodies with which they are in contact.

AEROSOL. Fine particles of solid or liquid suspended in air. Recently used to denote almost any dispersion in air. Technological interest, however, has been largely confined to particle sizes within the range of 0.1 to 100 microns diameter.

AGGLOMERATION. The property of particles to cohere, thereby increasing apparent particle size.

AMBIENT. Surrounding meteorological conditions such as ambient temperature, humidity, and pressure.

AMMUNITION. 1. All bullets, projectiles, rockets, grenades, torpedoes, bombs, and guided missiles with their necessary propellants, primers, fuzes, detonators, and charges of conventional explosive, nuclear explosive, chemical, or other materials. 2. In the broadest sense the term is not limited to materials used against an enemy, but includes all explosives, explosive devices, pyrotechnics, and pyrotechnic devices. Ammunition may be used for illumination, signaling, saluting, mining, digging, cutting, accelerating, decelerating, catapulting personnel or materiel, operating or stopping mechanisms, demolition, decoying, practice, training, guarding, game hunting, and pure sport. 3. In the most restricted sense the term includes a complete round and all its components; that is, the material required for firing a weapon such as a pistol, rifle, or cannon, from which a projectile is thrown. Generally the term is used or taken in its broadest sense (sense 2) unless a more restricted sense is indicated or is implied.

ANTIAGGLOMERANT. An additive used to prevent clustering or cohesion of particles.

APPARENT DENSITY. The ratio of mass to volume of a finely powdered material, under stated conditions, which is always less than true density. Sometimes called loading density. Because apparent density depends on the method used to obtain it, the method should always be specified. See BULK DENSITY.

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ARM. To make ammunition ready for functioning, as by removal of safety devices or alignment of the elements in the explosive train of the fuze.

ARMING DEVICE. A safety device that prevents a fuze from functioning or being in readiness to function until a selected interval has elapsed. Often called a safety and arming (S & A) device.

ARRHENIUS EQUATION. Represents the influence of temperature upon the rate of chemical reaction. $K = e^{-E/RT} + \text{constant}$. Where $e = 2.718$, E is activation energy, K is the specific reaction rate, R is the gas constant, and T is absolute temperature.

ASH. Combustion products, usually in the form of slag or crust, accumulating at the surface, along the cavity wall, and immediately beyond the flame area, which tend to interfere with combustion and visibility of the flame or colored smoke or pyrotechnic ammunition.

ATOMIZED. Reduced to fine particles, essentially spherical.

ATTENUATION. The lessening of any signal or effect, such as sound or light, with respect to time or distance.

AUXILIARY PARACHUTE. A parachute that augments or initiates the operation of the main parachute.

AVERAGE BURNING RATE. The arithmetic mean (statistical average) burning rate of pyrotechnic or explosive mixtures at specific pressures and temperatures. Dimension (length/time or mass/time).

BALLING. A method of preparing relatively uniform powder size in the form of balls.

BALLISTICS. The science of the propulsion, flight, and fragmentation of projectiles and missiles. Exterior ballistics deals with the forces on projectiles while in flight; interior ballistics deals with the forces of projectiles in a gun or the reaction that takes place within the motor of a rocket; terminal ballistics deals with the effect of projectiles or missiles on a target at the time of bursting or at the end of their trajectory.

BARATOL. An explosive composed of barium nitrate and TNT. Baratol, which is less brisant than TNT, is used as burster charge for colored marker projectiles.

BARRICADE. A structure, shield, or mount to protect personnel, equipment, or facilities. Used to deflect or confine the blast or fragmentation effects of explosives or deflagrations. A barricade is used during loading and testing of explosives and pyrotechnics.

BARRIER. A material designed to withstand penetration of bullets, shell fragments, sparks, or water, oils, moisture, or heat.

BASE EJECTION. A projectile that ejects its contents from its base. Usually the ejecting force is an expelling charge, actuated by a fuze. Various special purpose projectiles such as illuminating, leaflet, and some smoke projectiles, are of the base ejection type. See CHARGE, EXPELLING; EJECTION.

BASE IGNITION. A signal or other munition that ignites from the base with subsequent emission of smoke or chemical.

BASE PLATE. A metal plate covering the base of a projectile.

BASING, TRACER BULLET. Bullet basing is turning the periphery of the cylindrical base end of thin section bullet jackets toward the center of the cavity to produce a predetermined radius and restriction at the open rear end of the bullet.

BEE HIVE. A temporary storage building for explosives. The name arises from its shape. See also DOG HOUSE; IGLOO.

BICKFORD FUSE. A safety fuse having a core of black powder enclosed within a tube of woven threads, surrounded by various layers of waterproof textile for sheathing. The fuse burns at specific rates.

BINDER. Compositions that hold together a charge of finely divided particles, and increase the mechanical strength of plugs or pellets of these particles when consolidated under pressure. Binders usually are resins, plastics, asphaltics, or hard waxes used dry or in solution.

BLACKBODY. Any object that completely absorbs all radiation incident upon it, or conversely, a body that at any given temperature radiates maximum possible energy.

BLACK POWDER. A low explosive consisting of an intimate mixture of potassium or sodium nitrate, charcoal, and sulfur. It is easily ignited and is friction sensitive. Formerly used as a propellant, but now used almost exclusively in propellant igniters and primers, in fuzes to give short delays, in blank ammunition, and as spotting charges in practice ammunition. See MEAL POWDER.

BLAST. Specifically, the brief and rapid movement of air or other fluid away from a center of outward pressure, as in an explosion; the pressure accompanying this movement. This term is also commonly used as the equivalent of "explosion," but the two terms may be distinguished.

BLASTING CAP. A small thin-walled cylindrical case containing a sensitive explosive, such as lead azide. Used as a detonator to set off another explosive charge. The explosive in the blasting cap is fired either by a burning fuse or by electricity. Also called a DETONATOR, which see.

BLIND. A fired tracer round that does not ignite in the gun, and which shows no visible trace over any part of the trajectory.

BLOWBACK. (Primer) The release of initiation products away from the intended direction.

BLOWBY. The bypassing of one element in an explosive train.

BOMB. In a broad sense, an explosive or other lethal agent, together with its container or holder, which is designed to be dropped from an aircraft. In a pyrotechnic sense bombs can be classified as follows: Atomic simulator bomb. A pyrotechnic bomb used to simulate an atomic bomb for training purposes. Closed bomb. A test device used to evaluate the thermochemical characteristics of combustible materials. Also called a "closed chamber." The closed bomb is a thick walled, alloy steel cylinder with a removable threaded plug in each end. One plug contains the ignition system, the other plug is used to record pressure-time data. The bomb is cooled by a water jacket. The closed bomb is used to determine the linear burning rate, relative quickness, and relative force, under varying conditions of pressure and temperature of propellants. Fire or incendiary bomb. An item designed to be dropped from an aircraft to destroy or reduce the utility of a target by the effects of combustion. It contains an incendiary mixture that spreads on impact to burn or envelope in flames any material targets. When empty or inert loaded an incendiary bomb may be used for training purposes. Example: BOMB, FIRE: 750-lb, M116A1; BOMB, FIRE: 750-lb, MK 77 Mod O. BOMB, INCENDIARY: 4-lb, TH3, AN-M50A3. Napalm bomb. A fire bomb filled with napalm, a thickened petroleum oil. Primarily an antipersonnel weapon and often distinguished from an incendiary bomb, which is used primarily against installations or materiel. Phosphorus bomb. A smoke bomb filled with phosphorus, especially white phosphorus. Photoflash bomb. A bomb containing photoflash mixture. It is designed to function at a predetermined distance above the ground, to produce a brilliant light of short duration for photographic purposes. Example: BOMB, PHOTOFLASH: M122 (w/o burster); BOMB, PHOTOFLASH: 100 lb, AN-M46; BOMB, PHOTOFLASH: 150-lb, M120A1; BOMB, PHOTOFLASH: 150-lb, empty, M120. Target identification bomb. An aerial bomb that, upon impact, produces a relatively prolonged and conspicuous effect, such as a bright colored light, which provides a means of locating and identifying the target by other aircraft. Example: BOMB, TARGET IDENTIFICATIONS: SMOKE, MK72 Mod O. Unexploded bomb. A bomb that fails to explode on impact or immediately thereafter. It is considered to be a delayed action bomb until the contrary is proved.

BOOM POWDER. A pyrotechnic ignition mixture designed to produce many incandescent particles. A typical boom composition is:

Ingredient	Parts by Weight
Iron Oxide	50
Titanium (powdered)	32.5
Zirconium (powdered)	17.5

plus about 1 part of cellulose nitrate as a binder.

BOOSTER. 1. An assembly of metal parts and explosive charge provided to augment the explosive component of a fuze, to cause detonation of the main explosive charge of the munition. May be an integral part of the fuze. The explosive in the booster must be sensitive enough to be actuated by the small explosive elements in a fuze, and powerful enough to cause detonation of the main explosive filling. 2. An auxiliary propulsion system, employed in the early launching phase of a missile, used in addition to the principal propelling means. It may be released from the missile when its impulse has been delivered.

BRIGHTNESS. The luminous intensity (I) of any surface (a) in a given direction per unit of projected area of the surface as viewed from that direction; expressed as $B = \frac{dI}{da} (\cos \theta)$, where θ is the angle between the direction of observation and the normal to the surface.

BRIGHTNESS PYROMETER. A photoelectric device for measuring brightness.

BRISANCE. The shattering ability of explosives, usually measured in amount of sand crushed in a closed, heavy walled container.

BULK DENSITY. The mass per unit volume of a bulk material such as grain, cement, coal. Used in connection with packaging, storage, or transportation. A commercial rather than a laboratory term. See APPARENT DENSITY.

BURNING. A rapid evolution of energy through chemical reaction between a fuel and an oxidizing agent. See COMBUSTION. Burning rate is the rate of propagation of a pyrotechnic mixture. The burning time is the time elapsed between initiation and completion of reaction of a pyrotechnic mixture. Burning time depends on many factors such as length of column, degree of consolidation, temperature, pressure, percentage of ingredients and their particle size.

BURST. Explosion of a munition.

BURST ALTITUDE. Height at which a munition functions or is designed to function.

BURST DURATION. The time of persistence of a cloud of burning incandescent particles.

BURST, TRACER. A pyrotechnic composition that explodes inside a projectile cavity with a loud report or a large flash at some point along the trajectory after leaving the gun barrel.

BURSTER. An explosive charge used to break open and spread the contents of projectiles, bombs, or mines. Syn. Burster charge.

BURSTER TUBE. The tube that holds the burster in a chemical projectile.

BUTTER. To apply a paste-like mixture with a spatula or knife.

CALCINED. Reduced to a powder by the action of heat. To expel volatile matter.

CANDLE. 1. An item or that portion of an item which, by its progressive combustion, produces smoke or light over a comparatively long period of time. 2. The unit of luminous intensity. The unit used in the United States is a specified fraction of the average horizontal candlepower of a group of 45 carbon-filament lamps preserved at the National Bureau of Standards, when the lamps are operated at specified voltages. This unit is identical within the limits of uncertainty of measurement, with the International Candle established in 1909 by agreement among France, Great Britain, and the United States and adopted in 1921 by the International Commission on Illumination.

The international agreement of 1909 fixed only the unit at low color temperatures as represented by carbon-filament lamps. In rating lamps at higher temperatures, differences developed between the units used in different countries. In 1937 the International Committee on Weights and Measures adopted a new system of units based upon (1) assigning 60 candles per square centimeter as the brightness of a blackbody at the temperature of solidifying platinum, and (2) deriving values for standards having other spectral distributions by using accepted luminosity factors.

CANDLEPOWER. (cp) The luminous intensity (I) expressed in candles, when F is luminous flux, and W is the solid angle in steradians.

$$I = \frac{dF}{dW}$$

CANDLESECOND. A measure of total luminous energy transmitted when a source of luminous intensity of one candle acts for one second.

CANISTER. An inner container or cylinder in a projectile containing materials for special terminal effects, such as smoke, propaganda leaflets, chaff, or metal fragments. The container is designed to open up at some predetermined point after launching. Example: CANISTER, SMOKE: 5-INCH PROJECTILE; WP M5; CANISTER, SMOKE: 105-MM PROJECTILE, HC, M1; CANISTER, SMOKE: 155-MM PROJECTILE, GREEN, M3.

CARTRIDGE. An explosive item designed to produce gaseous products of combustion under pressure, for performing a mechanical operation other than the common one of expelling a projectile. A photoflash cartridge is a cartridge used for making aerial photographs from low altitudes during reconnaissance missions. Consists of a photoflash charge and delay fuze, and is assembled in a primed cartridge case together with a small propelling charge. Example: CARTRIDGE: PHOTOFLASH: M112 or M112A1, 1-sec delay; CARTRIDGE, PHOTOFLASH: M112 or M112A1, 4-sec delay. A practice photoflash cartridge is a cartridge used for training purposes, to simulate release and firing of photoflash cartridges. Example: CARTRIDGE; PHOTOFLASH, PRACTICE: M124. A signal practice bomb cartridge is an explosive inserted in the nose of a practice bomb. It is detonated upon impact and produces a puff of white smoke. Example: CARTRIDGE, SIGNAL, PRACTICE BOMB: MK6 Mod O, w/fuze, MK247 Mod O; CARTRIDGE, SIGNAL, PRACTICE BOMB: AN-MK4 Mod 1; CARTRIDGE, SIGNAL, PRACTICE BOMB: miniature, MK5 Mod O.

CASE. A box, sheath, or covering used to house ordnance materials.

CASTING. The procedure for loading molten charges into a container, and allowing to harden. See MELT LOADING.

CATALYST. 1. A substance that alters the rate of a reaction, but may be recovered unaltered at the end of the reaction. 2. A promoter used in plastics.

CAVITY. (Cavitation) An air space within mixtures that usually results in nonuniform burning or premature bursting.

CAVITY GEOMETRY. Specifically, those dimensions that affect the performance characteristics of a pyrotechnic or smoke composition, such as length, diameter, effective area, and configuration.

CHARGE, EXPELLING. Small charge of black powder or other low explosive in a base ejection projectile to eject contents, such as smoke canisters from the projectile. See BASE EJECTION.

CHARGE, FLASH. 1. A readily ignitible explosive charge used in ignition elements of electric primers and detonators. It usually ignites a subsequent charge of lesser sensitivity and greater brisance. 2. Pyrotechnic charge used in flash producing items such as photoflash cartridges, bombs, or spotting devices. See PHOTOFLASH COMPOSITION.

CHARGE, SHAPED. An explosive charge with a shaped cavity so that the explosive energy is focused to move in one direction. Sometimes called "cavity charge." Called "hollow charge" in Great Britain. Use of the term shaped charge generally implies the presence of a lined cavity.

CHARGE, SIGNAL, EJECTION. An explosive device designed to eject a signal from an underwater mine when used for training, Example: CHARGE, SIGNAL, EJECTION: MK3 Mod O.

CHARGE, SPOTTING. See SPOTTING CHARGE.

CHEMICAL AGENT. A substance used for riot control, incapacitating or casualty effect. Smokes and incendiaries are also classified as chemical agents.

CHEMICAL AMMUNITION. Any ammunition containing casualty agents, riot control agents, incendiaries, and burning-type signaling or screening smoke mixtures as the primary filler.

CHIMNEY EFFECT. The characteristic of hot gases to rise rapidly prior to any horizontal motion. In smoke producing munitions, when hot ashes accumulate at the signal orifice and cause flaming of the smoke producing products this condition is sometimes referred to as chimney effect. For flares, when a flare case is unconsumed during burning obscuring part of the light produced and reducing its luminosity, this undesirable condition is also referred to as chimney effect.

CIE SCALE. Formerly known as the ICI scale. A scale of color values developed by the "Commission Internationale de l'Eclairage," (CIE), International Commission on Illumination (ICI).

CIGARETTE BURNING. In rocket propellants, black powder, gasless elements, and pyrotechnic candles, the type of burning induced in a solid grain by permitting burning on one end only, so that the burning progresses in the direction of the longitudinal axis.

CLOUD. See SMOKE.

CLUSTER. 1. A collection of small bombs held together by an adapter for dropping. A cluster of fragmentation bombs so arranged that more than one bomb can be suspended and dropped from a single station of an airplane bomb rack. 2. A pyrotechnic signal consisting of a group of stars.

COLOR BURST UNIT. A unit containing a dye material placed in the nose of target projectiles, which produces a distinguishing color upon functioning of the fuze.

COLOR CHARTS. Charts used as standards to determine colors both as to hue and tone. Charts commonly used are Munsell, Chroma, and CIE.

COLORED SMOKE. Products of a distinctive color formed by either volatilization and condensation or combustion. The basis for a colored smoke is a volatile dye, which upon condensing forms a colored cloud. The dye may be volatilized by explosion of a burster charge, as in a colored marker projectile or by combustion of a fuel mixed with the dye, as in a colored smoke candle. Colored smoke munitions are made in several forms, including projectiles, bombs, grenades, and candles. They may be used as signals, target markers, and zone identification markers. The most satisfactory smoke colors are red, green, yellow, and violet.

COLOR INTENSIFIER. A halogenated compound added to flare compositions that makes flame colors more saturated.

COLOR PERCEPTION. The ability to distinguish among color hues.

COLOR RATIO. 1. A number that designates both hue and tone. 2. The proportion of visible radiation of a specific wavelength to the total visible radiation; also called color value.

COLUMN LENGTH. The length of an explosive or pyrotechnic composition.

COMBUSTIBILITY. Capability of burning. Flammable. The relative combustibility of materials in storage is defined as: Hazardous--materials that by themselves or in combination with their packaging, are easily ignited and will contribute to the intensity and rapid spread of a fire. Moderate--materials and their packaging both of which will contribute fuel to a fire. Low--materials that will not normally ignite, but which, in combination with their packaging, will contribute fuel to a fire. Noncombustible--materials and their packaging that will neither ignite nor support combustion.

COMBUSTION. A continuous, rapid chemical process accompanied by the evolution of energy, commonly the union of a fuel and an oxidizing agent. See BURNING.

COMPATIBILITY. Ability of materials to be stored intimately without chemical reaction occurring. Incompatibility may result in loss of effectiveness, or may be very hazardous.

COMPOSITION, PYROTECHNIC. A physical mixture of finely powdered fuel and oxidant, with or without additives, to produce a desired effect.

CRIMP. To put a bend or crease in metal, often used as a method of sealing or fastening two pieces of metal together. A cartridge case is crimped to a projectile.

CRITICAL HUMIDITY. The humidity at which the material is in equilibrium with its environment with respect to moisture content.

CURE TIME. Time required for polymerization of certain plastic materials to achieve a certain structural strength or surface hardness.

DARK IGNITER. Tracer that has period of darkness between ignition and visible flame (British). 2. Igniter for tracer with low luminous intensity to prevent blinding of the gunner. See DIM IGNITER.

DEACTIVATE. The act of rendering an explosive device inert or harmless.

DEAD-LOAD. Total pressure in pounds used to consolidate pyrotechnic compositions.

DEAD PRESSED. In an explosive, a highly compressed condition which tends to prevent the transition from deflagration to detonation that would otherwise take place.

DECOMPOSITION. The process of breaking down a material into more simple products. Disintegration, dissociation.

DEFLAGRATION. Very rapid combustion sometimes accompanied by flame, sparks, or spattering of burning particles. Deflagration, although classed as an explosion, generally implies the burning of a substance with self-contained oxygen so that the reaction zone advances into the unreacted material at less than the velocity of sound in the unreacted material. The term is often used to refer to the action of a high explosive projectile that upon impact with a target does not produce the usual effects of a high-order detonation. Strictly speaking, the term low-order detonation should be used to describe such a phenomenon if it is intended to connote a detonation at lower than the stable detonation velocity of the explosive. The term deflagration should be used if it is intended to connote a burning reaction. See EXPLOSION.

DEGRESSIVE BURNING. Propellant granulation in which the surface area of a grain decreases during burning. The degressive burning of a propellant is sometimes termed degressive granulation or regressive burning. See PROGRESSIVE BURNING.

DELAY. A pyrotechnic, mechanical electronic, or explosive train component that introduces a controlled time delay in some element of the arming or functioning of a fuze mechanism.

DELAY, ARMING. 1. The time or distance interval between the instant a piece of ammunition carrying the fuze is launched and the instant the fuze becomes armed. 2. The time interval required for the arming processes to be completed in a nonlaunched piece of ammunition. See DELAY.

DELAYED. When the term is used in connection with tracer bullet observation, it means that the bright trace starts late along the trajectory, but traces at least the minimum distance required.

DELAY ELEMENT. An explosive train component normally consisting of a primer, a delay column, and a relay detonator or transfer charge assembled in that order in a single housing to provide a controlled time interval.

DELAY, FUNCTIONING. The time or distance interval between initiation of the fuze and detonation of the bursting charge. See DELAY.

DELAY, GASLESS. Delay elements consisting of a pyrotechnic mixture that burns without production of gases.

DELAY IGNITER. A delay element used in conjunction with ignitible materials; such as igniter composition for tracer bullets. Delay igniters are designed to produce no visible exterior burning for a predetermined distance of the initial portion of the trajectory.

DENSITY OF CHARGE. The weight of pyrotechnic charge per unit volume of the chamber, usually expressed in grams per cubic centimeter.

DESICCANT. A drying agent.

DETONATE. To be changed by exothermic chemical reaction usually from a solid or liquid to a gas with such rapidity that the rate of advance of the reaction zone into the unreacted material exceeds the velocity of sound in the unreacted material; that is, the advancing reaction zone is preceded by a shock wave. See DETONATION.

DETONATING AGENT. Explosive used to set off other less sensitive explosives. Includes initial detonating agents, and other less sensitive explosives that may be used as intermediate explosive elements in a detonating train.

DETONATING CORD. A flexible fabric tube containing a filler of high explosive initiated by a blasting cap or electric detonator.

DETONATION. (Detonation Rate, Detonation Velocity) An exothermic chemical reaction that propagates with such rapidity that the rate of advance of the reaction zone into the unreacted material exceeds the velocity of sound in the unreacted material; that is, the advancing reaction zone is preceded by a shock wave. A detonation is an explosion. The rate of advance of the reaction zone is termed detonation rate or detonation velocity. When this rate of advance attains such a value that it will continue without diminution through the unreacted material, it is termed the stable detonation velocity. The exact value of this term depends upon a number of factors, principally the chemical and physical properties of the material. When the detonation rate is equal to or greater than the stable detonation velocity of the explosive, the reaction is a high-order detonation. When the detonation rate is lower than the stable detonation velocity of the explosive, the reaction is a low-order detonation. See DETONATE; DETONATION WAVE; EXPLOSION.

DETONATION WAVE. The shock wave that precedes the advancing reaction zone in a high-order detonation. See DETONATION.

DETONATOR. 1. In an explosive train, that component which, when detonated by the primer in turn detonates a less sensitive explosive (usually the booster), or when containing its own primer, initiates the detonation in the train. A detonator can be activated by either an explosive impulse (a primer) or a nonexplosive impulse. When activated by a nonexplosive impulse, the detonator contains its own primer. Detonators are generally classified as percussion, stab, electric, or flash, according to the method of initiation. 2. An explosive charge placed in certain equipment and set to destroy the equipment under certain conditions. Preferred term in this sense is DESTRUCTOR, EXPLOSIVE.

DICHROMATION. A chemical treatment employing salts of chromium to metals or alloys to inhibit corrosion.

DILUENT. An additive, usually inert, used to regulate burning rate or temperature.

DIM IGNITER. Igniter composition for tracer bullets designed to produce weak or dimly visible trace, visible to gunner for a predetermined distance of the initial portion of the trajectory. See DARK IGNITER.

DISC, BLOWOUT. A thin, metal diaphragm, sometimes installed in a rocket motor as a safety measure against excess gas pressure.

DISPERSING AGENT. A surface active agent that tends to keep solid particles dispersed in a liquid medium.

DOG HOUSE: A small temporary storage space for explosives. See also BEE HIVE; IGLOO.

DRY BLEND. A mixture of dry powders.

DUD. An explosive munition that fails to explode although such was intended.

DWELL TIME. In press loading powders into cavities, the interval of time that the powder is held at the full loading pressure.

EFFICIENCY. Ratio of the actual performance of an operation to the ideal performance, often expressed as a percentage.

EJECTION. The throwing out of loose material or a canister from a munition, usually by an expelling charge; may occur after impact or at any preset altitude. See BASE EJECTION.

ELECTROSTATIC SENSITIVITY. See SENSITIVITY.

ELUTRIATION. The process of purifying by washing and straining or decanting.

EMISSION. Flow of electrons out of heated materials.

EMISSIVITY. The rate at which a solid or a liquid emits electrons when additional energy is imparted to the free electrons in the material by the action of heat, light, or other radiant energy or by the impact of other electrons on the surface.

EMITTERS. The component of a pyrotechnic flash or flame responsible for the development of the color.

END ITEM. An item developed to meet a stated requirement. Usually a combination of components, assemblies, or parts ready for their intended use, and not a component of a larger assembly.

ENDOTHERMAL. A reaction that occurs with the absorption of heat. Opposed to exothermal.

ENSIGN-BICKFORD FUSE. A powder train encased in a cotton or plastic sheath. See FUSE, BICKFORD.

ENTHALPY. A concept for any system defined by $H = E + PV$, where H is enthalpy, E is internal energy, P is pressure, and V is the volume. Often called the total heat. Change in enthalpy is the amount of heat added to, or subtracted from, a system in going from one state to another under constant pressure.

ENTROPY. The degree in which the energy of a system has ceased to be available. $dS = \frac{dQ}{T}$, where S is entropy, Q is heat absorbed by a system, and T is absolute temperature.

ENTROPY OF ACTIVATION. Related to the probability of the activated state (P), which is the essential intermediate in all reactions. $PZ = e^{\Delta SR}$ (KT/h) where S is entropy, R is the gas constant, and Z and KT/h are essentially constant.

EQUATION OF STATE. Any of several equations relating the volume, temperature, and pressure of a system.

EXOTHERMAL. A process characterized by the evolution of heat. Opposite of endothermal.

EXPLODE. To be changed in chemical or physical state usually from a solid or liquid to a gas (as by chemical decomposition or sudden vaporization) so as to suddently transform considerable energy into the kinetic form. See EXPLOSION.

EXPLOSION. A chemical reaction or change of state that is effected in an exceedingly short space of time with the generation of a high temperature and generally a large quantity of gas. An explosion produces a shock wave in the surrounding medium. See DEFLAGRATION.

DETONATION. A confined explosion is an explosion occurring, as in a closed chamber, where the volume is constant. An unconfined explosion is an explosion occurring in the open air where the (atmospheric) pressure is constant.

EXPLOSION PROOF. Equipment and components constructed so that either they will not spark or that dusts and vapors are barred from places where sparking does occur.

EXPLOSIVE. A substance or mixture of substances that may be made to undergo a rapid chemical change, without an outside supply of oxygen, with the liberation of large quantities of energy generally accompanied by the evolution of hot gases. Explosives are divided into two classes; high explosives and low explosives, according to their rate of reaction in normal usage. Certain mixtures of fuels and oxidizers can be made to explode and are considered to be explosives. However, a substance such as a fuel, which requires an outside source of oxidizer, or an oxidizer, that requires an outside source of fuel to explode, is not considered an explosive.

EXPLOSIVE, CONVENTIONAL. A nonatomic explosive.

EXPLOSIVE FILLER. Main explosive charge contained in a projectile, missile, bomb, or the like. See CHARGE, as modified.

EXPLOSIVE LIMIT. Maximum weight of explosive that may be allowed in any particular storage, loading, or handling area.

EXPLOSIVE TRAIN. A train of combustible and explosive elements arranged in order of decreasing sensitivity inside a fuze, projectile, bomb, gun chamber, or the like. The explosive train accomplishes the controlled augmentation of a small inpulse into one of suitable energy to actuate main charge of the munition. A fuze explosive train may consist of a primer, a detonator, a delay, a relay, a lead and booster charge, one or more of which may be either omitted or combined. If the bursting charge is added to the foregoing train it becomes a bursting charge explosive train. A propelling charge explosive train might consist of a primer, igniter or igniting charge, usually black powder, and finally, any of the various types of propellants. See LEAD, EXPLOSIVE.

FILLER. 1. An ammunition charge. 2. An inert additive.

FILTERING. Undesirable loss of smoke density and hue due to ash formation causing degradation of the dye.

FILTER (OPTICAL). A type of optical equipment that will transmit or absorb light of a certain range of wavelengths.

FIRECRACKER. A small paper cylinder containing an explosive and a fuse. It is used to simulate the noise of an explosive charge.

FIRST FIRE. The igniter composition used with pyrotechnic devices that is loaded in direct contact with the main pyrotechnic charge. A pyrotechnic first fire composition is compounded to produce a high temperature and hot slag. The composition must be readily ignitible, and capable of igniting the underlying pyrotechnic charge. See also STARTING MIX; IGNITER.

FISSURES. Cracks in pressed or cast pyrotechnic mixtures, which are undesirable because they increase burning areas and rates, and can affect physical characteristics.

FLAKES. Extremely thin, small particles of metal.

FLAME. 1. A chemical reaction or reaction product, partly or entirely gaseous, that yields heat and light. 2. State of blazing combustion. A flame profile is a temperature profile of any particular flame. Flame temperature is the calculated or determined temperature of the flame.

FLAMING. Production of a flame that is undesirable in compositions designed for dissemination.

FLARE. A pyrotechnic munition designed to produce a single source of intense light for relatively long durations for target or airfield illumination, signaling, or other purposes. An aircraft flare is a pyrotechnic munition designed for use from aircraft. Produces a single source of intense light for signaling, target, or airfield illumination. Example: FLARE, AIRCRAFT; guide, red, T7E1; FLARE, AIRCRAFT; guide, white, T3. An airport flare is a pyrotechnic munition designed to identify and illuminate an airport in the absence of other illumination. A chute flare is a popular name for parachute attached to a flare. Float flare is a signal launched from aircraft, to mark a location at sea. It floats on the surface and emits smoke and flame for up to an hour. Guide flare is an electrically ignited aircraft flare for attachment to an aerial bomb, which produces very bright light, either white or colored, to mark the position of the bomb and permit its guidance to the target. An illuminating flare is any pyrotechnic device that produces a brilliant, single source light of relatively long duration. A surface flare is a pyrotechnic item designed for use in surface positions, ground or water. Produces a single source of intense light for illumination of airport runways, warning of infiltrating enemy troops, and other purposes. Example: FLARE, SURFACE: airport, M76; FLARE, SURFACE: float, MK15 Mod O; FLARE, SURFACE: trip, M49; FLARE, SURFACE: trip, parachute, M48; FLARE, SURFACE: trip wire, MK1 Mod O. A trip flare is a surface flare actuated by, and thus serving as a warning of the approach of, infiltrating enemy troops. It is booby trapped and in one type is attached to a parachute that is projected into the air.

FLARE, GUIDED MISSILE. A pyrotechnic device that produces an intense light for the purpose of visually tracking a guided missile during its flight to a target. Excludes TRACER, GUIDED MISSILE.

FLARE MIXTURE. A pyrotechnic composition, compounded to produce a brilliant light of relatively long duration, either white or colored.

FLARE, PARACHUTE. Any flare attached to a parachute and designed to provide intense illumination. Used to light targets for night bombing, for reconnaissance, or to furnish light for aircraft emergency landings. A hand fired parachute flare is a complete self-contained device fired from the hand, and which provides a rocket projected, parachute borne, pyrotechnic light.

FLASH. Indicates in the case of simulators and other pyrotechnic items, that item is intended to produce a flash.

FOOT CANDLE. The unit of illumination when the foot is taken as the unit of length. It is the illumination on a surface one square foot in area on which there is a uniformly distributed flux of one lumen, or the illumination produced at a surface all points of which are at a distance of one foot from a uniform point source of one candle.

FORMULATION. A pyrotechnic composition. See COMPOSITION, PYROTECHNIC.

FUEL. 1. Any substance used to produce heat by burning. 2. A combustible material used in pyrotechnic composition, for example, powdered metals and resins.

FUSE. (Not to be confused with FUZE.) An igniting or explosive device in the form of a cord, consisting of a flexible fabric tube and a core of low or high explosive. Used in blasting and demolition work, and in certain munitions. A fuse with a black powder or other low explosive core is called a "safety fuse," or "blasting fuse." A fuse with a PETN or other high explosive core is called "detonating cord" or "primacord."

FUSE, BICKFORD. A safety fuse, having a core of black powder enclosed within a tube of woven threads, surrounded by various layers of textile, waterproof material and sheathing. Burns at specific rates.

FUSEE. (pronounced "fu-zee"; not to be confused with FUSEE (rocket, French)). 1. An igniter squib for a rocket motor. 2. A pyrotechnic signal, used as a safety signal on railroads, normally consisting of a tube or cartridge with a spike point base. When placed in an erect position and ignited, the cartridge burns with a white or colored light for a definite period of time. Example: FUSEE, WARNING, RAILROAD: red, 5-min.; FUSEE, WARNING, RAILROAD: red, 15-min.

FUZE. 1. A device with explosive or pyrotechnic components designed to initiate a train of fire or detonation in ammunition. Types of fuzes are distinguished by modifying terms forming part of the item name. 2. To equip an item of ammunition with a fuze.

GAS. An obsolete term for chemical agent. The preferred terms are casualty agent, toxic chemical agent, or riot control agent.

GRANULATION. Size and shape of grains of pyrotechnic ingredients. See GRIST.

GRAYBODY. A temperature radiator whose spectral emissivity is less than that of a blackbody. The spectral emissivity of a graybody remains constant through the spectrum.

GRENADE. A small explosive or chemical missile, originally designed to be thrown by hand, but now also designed to be projected from special grenade launchers, usually fitted to rifles or carbines. Grenades may be classified in a broad sense as hand and rifle. Many varieties and variations of these have been used, including a number of improvised ones. Some of the principal types and designations used in recent years are identified by the following. Chemical grenade is a general term for any hand or rifle grenade charged with a smoke of other chemical agent. Burning type chemical grenade is any hand or rifle grenade that releases its chemical by a burning action. A bursting type chemical grenade is a general term for any hand or rifle grenade that releases its chemical by a bursting action. Illuminating grenade is a hand or rifle grenade designed to provide illumination by burning. It may be used also as a trip flare or as an incendiary device. Incendiary grenade is a hand grenade filled with incendiary materials such as thermite, and used primarily to start fires. Practice grenade is a hand or rifle grenade used for practice purposes. Riot grenade is a hand

grenade of plastic or other nonfragmenting material, containing a charge of riot control agent and a detonating fuze with short delay. The agent is released by a bursting action. Smoke grenade is a grenade containing a smoke producing mixture. Used for screening or signaling. White phosphorus grenade is a hand or rifle grenade containing a main charge of white phosphorus and a small explosive burster charge for scattering the main charge. Used for smoke and some incendiary effect.

GRIST. Particle size of pyrotechnic material. See GRANULATION.

GROUND SIGNAL. A pyrotechnic signal fired from ground level.

HAND HELD. A rocket propelled, stabilized signal that has the launching mechanism integral with the signal.

HANGFIRE. A brief undesired delay in the functioning of an ammunition item. Usually refers to delay in ignition of a propelling charge. See MISFIRE.

HERMETIC SEAL. A seal made impervious to air and fluids.

HIGH EXPLOSIVE. An explosive that when used in its normal manner detonates, rather than deflagrates or burns; that is, the rate of advance of the reaction zone into the unreacted material exceeds the velocity of sound in the unreacted material. High explosives are divided into two classes: primary high explosives, and secondary high explosives, according to their sensitivity to heat and shock. (NOTE: This division is not accepted by some authorities who maintain that high explosives and primary explosives are entirely separate entities.) Whether an explosive reacts as a high explosive or as a low explosive depends on the manner in which it is initiated and confined. For example, a double base propellant when initiated in the usual manner is a low explosive. However, this material can be made to detonate if the propellant is initiated by an intense shock. Conversely, a high explosive such as TNT, under certain conditions, can be ignited by flame and will burn without detonating. See LOW EXPLOSIVE.

HYGROSCOPICITY. The tendency of a substance to absorb moisture from its surroundings; specifically the absorption of water vapor from the atmosphere.

IGLOO. A storage house for explosives. See BEE HIVE, DOG HOUSE.

IGNITER. A readily initiated pyrotechnic composition that is used to function the main charge. See FIRST FIRE, STARTING MIX.

IGNITER TRAIN. Step-by-step arrangement of charges in pyrotechnic munitions by which the initial fire from the primer is transmitted and intensified until it reaches and sets off the main charge. Also called "burning train." Explosive munitions use a similar series, called an "explosive train." See EXPLOSIVE TRAIN.

IGNITIBILITY. Statement of the ease with which the burning of a substance may be initiated.

ILLUMINANT COMPOSITION. A mixture of materials used in the candle of a pyrotechnic device to produce a high intensity light as its principal function. Materials used include a fuel (reducing agent), an oxidizing agent, and a binder, plus a color intensifier and waterproofing agent. The mixture is loaded under pressure in a container to form the illuminant charge.

ILLUMINATING. Indicates, in the case of pyrotechnic ammunition, that the munition is intended primarily for illuminating purposes. Usually contains a flare and may contain a parachute for suspension in the air.

ILLUMINATION. Illumination is the density of the luminous flux on a surface; it is the quotient of the flux (F) divided by the area (A) of the surface when the latter is uniformly illuminated. $E = dF/dA$. The term illumination is also commonly used in a qualitative or general sense to designate the act of illuminating or the state of being illuminated. Usually the context indicates which meaning is intended, but it is desirable to use the expression amount of illumination to indicate that the quantitative is intended.

INCENDIARY. 1. To cause or to design to cause fires. 2. In nomenclature it designates a highly exothermic composition or material that is primarily used to start fires or render equipment unusable by heat action.

INCREMENT. The amount of pyrotechnic composition added to the charge during the process of loading.

INERT. Descriptive of condition of a munition, or component thereof, that contains no explosive, pyrotechnic, or chemical agent.

INITIATION. 1. As applied to an explosive item, the beginning of the deflagration or detonation of the explosive. 2. The first action in a fuze that occurs as a direct result of the action of the functioning medium. 3. In a time fuze, the starting of the action that is terminated in the functioning of the fuzed munition.

INITIATOR. A device used as the first element of an explosive train, such as a detonator or squib, which, upon receipt of the proper mechanical or electrical impulse, produces a burning or detonating action. It generally contains a small quantity of a sensitive explosive.

INTERNATIONAL CANDLE. An international unit of luminous intensity that is the light emitted by five square millimeters of platinum at solidification temperature.

IR WINDOWS. Frequencies of electromagnetic radiation that have the least attenuation by the atmosphere. Important attenuators of IR radiation are water vapor and carbon dioxide. In upper atmospheres, minor gas constituents such as N_2O, O, CO become more important than water. Important windows exist for wavelengths between 3.6 to 4.7 micron wavelength and 8 to 13 micron wavelength.

IRRITANT GAS. An obsolete term for a riot control agent or a lachrymator.

ISOBARIC ADIABATIC--FLAME TEMPERATURE. Adiabatic flame temperature attained in a constant pressure system.

ISOCHORIC ADIABATIC--FLAME TEMPERATURE. Adiabatic flame temperature attained in a constant volume system.

LACHRYMATOR. A chemical that irritates the eyes and produces tearing. Commonly called tear gas. Also spelled lacrimator.

LEAD, EXPLOSIVE. (Rhymes with feed). An explosive train component that transmits the detonation from one explosive component to a succeeding component, as from detonator to booster charge. Also called "explosive lead." See EXPLOSIVE TRAIN.

LEAKER. 1. Term for bomb projectile or pyrotechnic item filled with a chemical agent or composition that is leaking the contents, and contaminating the surrounding area. 2. An item that permits vapors or liquids to enter or leave because of improper sealing.

LINEAR BURNING RATE. The distance normal to any burning surface of the pyrotechnic column burned through in unit time.

LOADING DIE. A heavy walled metallic cylinder employed to confine a charge or pyrotechnic component during consolidation.

LOW EXPLOSIVE. (LE) An explosive that when used in its normal manner deflagrates or burns rather than detonates; that is, the rate of advance of the reaction zone into the unreacted material is less than the velocity of sound in the unreacted material. Low explosives include propellants, certain primer mixtures, black powder, photoflash powders, and delay compositions. Whether an explosive reacts as a high explosive or a low explosive depends on the manner in which it is initiated and confined. For example, a double base propellent when initiated in the usual manner is a low explosive. However, this material can be made to detonate if the propellant is initiated by an intense shock. Conversely, a high explosive like TNT, under certain conditions, can be ignited by flame and will burn without detonating. See HIGH EXPLOSIVE.

LOW ORDER BURST. Functioning of a projectile or bomb in which the explosive fails to attain a high order detonation. Usually evidenced by the breaking of the container into a few large fragments instead of a large number of smaller fragments. See DETONATION.

LUMINOUS EFFICIENCY. The luminous efficiency of radiant energy is the ratio of the luminous flux to the radiant flux. Luminous efficiency is usually expressed in lumens per watt of radiant flux. It should not be confused with the term efficiency as applied to a practical source of light, because the latter is based upon the power supplied to the source instead of the radiant flux from the source. For energy radiated at a single wavelength, luminous efficiency is synonymous with luminosity factor. The reciprocal of the luminous efficiency of radiant energy is sometimes called the "mechanical equivalent of light." The value most commonly cited is the minimum "mechanical equivalent," that is, the watts per lumen at the wave length of maximum luminosity. The best experimental value is 0.00154 watt per lumen, corresponding to 650 lumens per watt as the maximum possible efficiency of a source of light. When expressed in terms of the new value of the lumen these numerical values become, respectively 0.001511 watt per (new) lumen and 660 (new) lumen per watt.

LUMINOUS INTENSITY. $I_j = dF/dw$: Luminous intensity, of a source of light, in a given direction, is the luminous flux on a small surface normal to that direction, divided by the solid angle (in steradians) the surface subtends at the source of light.

MACH NUMBER. (M) The ratio of the velocity of a body to that of sound in the medium being considered. At sea level, at the standard atmosphere, a body moving in air at a Mach number of one ($M = 1$) has a velocity of 1116.2 ft./sec. (the speed of sound in air under those conditions). Frequently shortened to "Mach."

MARKER. A pyrotechnic item used to point out a location on land or water. Frequently contains a dye or a burning mixture for marking a location.

MEAL POWDER. An unglazed black powder of very fine granulation. See BLACK POWDER.

MELT LOADING. Process of melting solids, explosives, dyes, and powders into projectiles and the like, to solidify. See CASTING.

MINE. An encased explosive or chemical charge placed in position. It detonates when its target touches or moves near it or when touched off by remote control. Two general types are land mines and underwater mines.

MISFIRE. Failure of a round of ammunition to fire after initiating action is taken. See HANGFIRE.

MIXTURE. See COMPOSITION, PYROTECHNIC.

MUZZLE BURST. Explosion of a projectile at the muzzle of a weapon, or at a very short distance from the muzzle.

MUZZLE FLASH. Flame at the muzzle of a gun after the projectile leaves the barrel. Commonly caused by ignition of propellant gases. Also can be heightened by ignition of broken or insufficiently consolidated propellant composition.

MUZZLE VELOCITY. The linear rate of motion of an object as it is expelled from a gun barrel or similar device.

NAPALM. Aluminum soap in powder form, used to gelatinize oil or gasoline for use in bombs or flame throwers.

NONHYGROSCOPIC. Does not absorb moisture from the air. Used frequently when referring to pyrotechnic ingredients.

NOSE. The foremost point or section of a bomb, missile, or the like. Indicates, in fuze nomenclature, that the fuze is to be attached to the nose of the munition for which it is intended; and, in the case of the component of a fuze, that the component is to be used with a nose fuze.

OBTURATE. To stop or close an opening so as to prevent escape of gas or vapor. To seal as in delay elements.

OGIVE. A curved or front section of a projectile or signal.

OXIDIZER. In an explosive or other chemical mixture, a substance that furnishes the reactant for burning the fuel, usually oxygen.

OXYGEN BALANCE. Ratio of self-contained oxygen to fuel in propellants, explosives, and pyrotechnics. Gives the extent that an explosive is deficient or overly rich in oxygen compared to the amount required for complete combustion.

PELLET. A consolidated cylindrical charge.

PELLETING. Process of consolidating cylindrical charges.

PHOTOFLASH COMPOSITION. A pyrotechnic charge that when loaded in a suitable casing and ignited, will produce a light of sufficient intensity and duration for photographic purposes. See CHARGE, FLASH.

PISTOL, PYROTECHNIC. A single shot device designed specifically for projecting pyrotechnic signals. This item may or may not be provided with a method of mounting to an adapter.

PISTOL, VERY. Former terminology for Pyrotechnic Pistol.

PREMATURE: A type of functioning in which a munition functions before the expected time of circumstance.

PRIMACORD. A trade name for a type of detonating cord that consists of a flexible fabric tube containing a filler of high-explosive PETN (pentaerythrotetranitrate). Used to transmit a detonation from a detonator to a booster or bursting charge. Sometimes used by itself to fell trees, dig ditches, and to demolish structures.

PRIMING COMPOSITION. A physical mixture of materials that is very sensitive to impact or percussion and, when so exploded, undergoes very rapid autocombustion. The products of such an explosion are hot gases and incandescent solid particles. Priming compositions are used for the ignition of primary high explosives, black powder igniter charges, propellants in small arms ammunition, and so on.

PRIMER. A relatively small and sensitive device used to initiate the functioning of an explosive, igniter train, or pyrotechnic charge; it may be actuated by friction, percussion, heat, pressure, or electricity.

PROGRESSIVE BURNING. Propellant granulation in which the surface area of the grain increases during burning. Sometimes called "progressive granulation." See DEGRESSIVE BURNING.

PROJECTILE. 1. A body projected by exterior force and continuing in motion by its own inertia. 2. A missile used in any type of gun. Sometimes applied to rockets and guided missiles although these do not fall within the stated definition. "Projectile" is preferred over "shot" or "shell."

PROJECTILE, COLORED MARKER. Projectile loaded with a charge consisting primarily of organic dye, and provided with a burster or bare ejection charge.

PROPELLANT. An explosive material whose rate of combustion is low enough, and its other properties suitable, to permit its use as a propelling charge. A propellant may be either solid or liquid. A single base propellant composition consists primarily of a matrix of nitrocellulose. A double base propellant composition contains nitrocellulose and nitroglycerine. A composite propellant composition contains an oxidizing agent in a matrix of binder.

PUNK, STICK. A preformed material in cylindrical form, which when ignited smolders without flame. Used for igniting safety fuse.

PYROPHORIC. Materials that will ignite spontaneously.

PYROTECHNIC CODE. Significant arrangement of the various colors and arrangements of signal lights or signal smokes used for communication between units or between ground and air.

PYROTECHNIC COMPOSITION. A mixture of materials consisting essentially of an oxidizing agent (oxidant) and a reducing agent (fuel). It is capable of producing an explosive selfsustaining reaction when heated to its ignition temperature.

PYROTECHNIC ITEMS. Devices used to produce sound, colored lights or smokes for signaling, a bright light for illumination, and time delays.

QUICKMATCH. Fast burning fuse made from a cord impregnated with black powder.

RAM. A metallic cylindrical piece used to compress or consolidate pyrotechnic charges in a mold or die.

RELAY. An explosive train component that provides the required explosive energy to reliably initiate the next element in the train. Specifically applied to small charges that are initiated by a delay element, and in turn, cause the functioning of a detonator.

SEDIMENTATION. The process of depositing large size particles in particle size analysis.

SELF-DESTROYING. When used in connection with a fuze or a tracer, self-destroying indicates that the projectile, rocket, or missile with which it is used will be destroyed in flight prior to ground impact in case the target is missed. See SELF-DESTRUCTION.

SELF-DESTRUCTION. Indicates projectiles designed to destroy themselves by fuze or tracer action, without outside stimulus, after flight to a range greater than that of the target. Self-destruction (also called self-destroying) features are used in antiaircraft ammunition where impact of unexploded projectiles or missiles would occur in friendly areas. See SHELL DESTROYING TRACER.

SENSITIVITY. Susceptibility of an explosive pyrotechnic component to react to externally applied energy or changes in environment.

SETBACK. 1. The relative rearward movement of component parts in a projectile, missile, or fuze undergoing forward acceleration during launching. These movements, and the setback force that causes them, are often used to arm or cause eventual functioning of the fuze. 2. Short for "setback force."

SHELL DESTROYING TRACER. A tracer, which includes an explosive element beyond the tracer element, that is designed to permit activation of the explosive by the tracer after the projectile has passed the target point but is still high enough to be harmless to ground troops. See SELF-DESTROYING.

SHORT TRACE. A trace that does not burn over the desired length of the trajectory.

SIGNAL. A pyrotechnic end item that produces illumination, smoke, or combination of these effects for identification, location, or warning. An illumination signal is designed to produce a light primarily, usually white, amber, red, or green; a signal flare. A smoke signal is designed to produce smoke; the smokes may be black, white, or various colors. A smoke and illumination signal produces a sign by production of light and smoke. Signals may be designed to be discharged from aircraft, ground positions, surface craft, or submarines.

SIGNAL KIT, ABANDON SHIP. A group of items consisting of a hand projector and pyrotechnic signals in a metal container designed for use with an abandon ship outfit.

SIGNAL KIT, PYROTECHNIC PISTOL. A group of items consisting of pyrotechnic pistol(s), pyrotechnic signals, and associated items in a container. See also: SIGNAL KIT, ABANDON SHIP.

SIGNAL LIGHT. General term indicating a signal, illumination or any pyrotechnic light used as a sign.

SIGNAL PISTOL. A single shot pistol designed to project pyrotechnic signals. See PISTOL, PYROTECHNIC.

SIGNAL ROCKET. A rocket that gives off some characteristic color or display that has a meaning according to an established code. It is usually fired from a signal pistol or a ground signal projector.

SIMULATOR. A pyrotechnic device used to simulate the effects of various military items for training purposes or decoys. Simulators have been devised for the following: booby traps, artillery flash, hand grenades, air and ground burst projectiles.

SMOKE. A particulate of solid or liquid particles of low vapor pressure that settles out slowly under gravity. In general, smoke particles range downward from about 5 micron diameter to less than 0.1 micron diameter.

Smokes are used militarily for signaling and screening. A signaling smoke is used for communication purposes and is based upon the volatilization of a dye, which upon condensing forms a colored cloud. The dye may be volatilized by detonation of a burster charge, as in a colored marker projectile, or by combustion of a pyrotechnic composition mixed with the dye, as in colored smoke grenades. A screening smoke is used to prevent observation of a particular area. It is primarily produced by volatilization of oil, by white phosphorus, or by metallic chlorides such as zinc chloride, which effectively scatter light. The cloud produced is called a smoke screen. There are three types of smoke screens: 1. A smoke blanket is used over friendly areas to hinder aerial observation and precision bombing. Smoke blankets are formed by smoke generators, mechanical generators used to volatilize oil, and smoke pots, which produce smoke by the combustion of a pyrotechnic composition. 2. Smoke haze is used mainly to conceal activities from observation and ground fire. Formed in much the same manner as smoke blankets. A haze is usually less dense than a blanket. 3. Smoke curtain is a dense vertical development used to restrict ground observation. May be produced by artillery weapons.

SPECTRAL EMISSIVITY. The spectral emissivity of a radiator at any given wavelength is the ratio of its radiant flux density to that of a blackbody at the same temperature and under similar circumstances. Except for luminescent materials, the emissivity can never be greater than one. See EMISSIVITY.

SPECTRUM. The entire range of electromagnetic radiation from the longest radio waves to the shortest cosmic rays and including all visible light.

SPOTTER TRACER. A subcaliber projectile used for fire control with a trajectory that closely matches the trajectory of a larger round. The point of impact is indicated by the terminal spotter explosion, which produces a display of flash, smoke, or flash and smoke. The path of the trajectory is indicated by the tracer and thus aids in directing the fire of a large caliber weapon.

SPOTTING CHARGE. A small charge, usually of black powder in a practice bomb, practice mine, or the like, to show the location of its point of impact. Also, occasionally, used in service ammunition. Also, the pyrotechnic composition used in spotter projectiles for terminal display. Example: CHARGE, SPOTTING, BOMB: M1A1 (for practice bomb,100 lb, M38A2) (black powder.); CHARGE, SPOTTING, BOMB: MK4 Mod 3; CHARGE, SPOTTING, BOMB: MK7 Mod 0; CHARGE, SPOTTING, MINE: practice, M8.

SQUIB. 1. Used in a general sense to mean any of various small size pyrotechnic or explosive devices. 2. Specifically, a small explosive device, similar in appearance to a detonator, but loaded with low explosive, so that its output is primarily heat (flash). Usually electrically initiated, and provided to initiate action of pyrotechnic devices and rocket propellants. An electric squib is a tube containing a flammable material and a small charge of powder compressed around a fine resistance wire connected to electrical leads or terminal. A squib is designed to electrically fire a burning type munition.

STABILITY. Ability of explosive or pyrotechnic materials to withstand long storage under service conditions.

STABILITY TEST. Accelerated test to determine the probable suitability of a pyrotechnic charge for long term storage under a variety of environmental conditions.

STAR. An aerial pyrotechnic signal of short duration that burns as a single colored light. Colors are usually white, amber, red, and green.

STARTING MIX. An easily ignited mixture that transmits flame from an initiating device to a less readily ignitible composition. See FIRST FIRE; IGNITER.

SURVEILLANCE. Observation, inspection investigation, test, study, and classification of pyrotechnic and explosive items in movement, storage, and use with respect to degree of serviceability and rate of deterioration.

THERMITE. An incendiary composition consisting of 2.75 parts black iron oxide (ferrosoferric oxide)and 1.0 part granular aluminum. Thermate (TH2 or TH3) is an incendiary mixture: TH3 contains thermite, barium nitrate, and sulfur; TH2 does not contain sulfur.

TOTAL EMISSIVITY. The total emissivity of a radiator is the ratio of its radiant flux density (radiancy) to that of a blackbody at the same temperature. See also EMISSIVITY; SPECTRAL EMISSIVITY.

TRACER. 1. A tracer bullet used primarily as an aid for directing the fire of a weapon and locating the target. 2. A tracer element for any projectile. 3. As part of ammunition nomenclature, indicates item is equipped with a tracer. A guided missile tracer is a pyrotechnic tracer that provides a sign to permit tracking of a guided missile. A tracer mixture is a pyrotechnic composition used for loading tracers. Also called "tracer composition."

VISIBILITY. The relative clearness with which objects stand out from their surroundings under good seeing conditions. Also called visual range. In meteorology "the visibility" means a distance--that distance at which it is just possible to distinguish a dark object against the horizon.

WARHEAD. (Rocket and Guided Missile) The portion of a rocket or guided missile containing the load that the vehicle is to deliver. It may be empty or contain high explosives, chemicals, instruments, or inert materials. It may include a booster, fuze(s), adaption kit, or burster. Excludes items that contain atomic weapon components.

WHISTLE. A pyrotechnic device that produces a whistling sound on combustion.

WINDOW. 1. IR window. 2. A type of confusion reflector, consisting of metal foil ribbon, but sometimes metalized only on one side. Also known as "chaff." Similar to, but shorter in length than "rope." May be dropped from planes or shot into the air in projectiles. Original use of the word "window" appears to have been strictly a matter of code.

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ENGINEERING DESIGN HANDBOOK

MILITARY PYROTECHNICS SERIES

PART ONE

THEORY AND APPLICATION

HEADQUARTERS, U.S. ARMY MATERIEL COMMAND APRIL 1967

HEADQUARTERS
UNITED STATES ARMY MATERIEL COMMAND
WASHINGTON, D. C. 20315

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ENGINEERING DESIGN HANDBOOK

MILITARY PYROTECHNICS SERIES
PART ONE--THEORY AND APPLICATION

This pamphlet is published for the information and guidance of all concerned.

(AMCRD-R)

FOR THE COMMANDER:

K. H. BAYER
Major General, USA
Acting Chief of Staff

OFFICIAL:

STANLEY J. SAWICKI
Colonel, GS
Chief, Administrative Office

DISTRIBUTION:
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HEADQUARTERS
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FOR THE COMMANDER:

OFFICIAL:

Wm. A. Gregory

WM. A. GREGORY
Colonel, GS
Chief, Administrative Office

CLARENCE J. LANG
Major General, USA
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PREFACE

The Engineering Design Handbook Series of the Army Materiel Command is a coordinated series of handbooks containing basic information and fundamental data useful in the design and development of Army materiel and systems. The handbooks are authoritative reference books of practical information and quantitative facts helpful in the design and development of Army materiel so that it will meet the tactical and the technical needs of the Armed Forces. The present handbook is one of a series intended to fill a longfelt need for an authoritative and comprehensive source of information on military pyrotechnics.

It is a common misconception to regard military pyrotechnics as being synonymous with fireworks. Military pyrotechnics is rapidly developing into a science which exploits all applicable scientific and engineering principles and practices.

This handbook, *Military Pyrotechnics, Part One, Theory and Application,* includes a chapter on the history of the pyrotechnic art, a chapter giving a general introduction to the application of pyrotechnic devices to military problems, and chapters on Physical-Chemical Relationships, Visibility, Production of Heat, Production of Light, and Production of Smoke.

Material for this handbook, except for Chapter 1, was prepared by the Denver Research Institute of the University of Denver, under the direction of Dr. Robert W. Evans. Material for Chapter 1, History of Military Pyrotechnics, was prepared by the McGraw-Hill Book Company Technical Writing Service. All material was prepared for the Engineering Handbook Office of Duke University, prime contractor to the Army Research Office-Durham. The preparation of this handbook was under the technical guidance of an interservice committee with representation from the Army Chemical Center, Ballistic Research Laboratories, Frankford Arsenal, Harry Diamond Laboratories and Picatinny Arsenal of the Army Materiel Command; the Naval Ammunition Depot (Crane), Naval Ordnance Laboratory and the Naval Ordnance Test Station. The chairman of this committee was Garry Weingarten of Picatinny Arsenal.

Elements of the U. S. Army Materiel Command having need for handbooks may submit requisitions or official requests directly to Publications and Reproduction Agency, Letterkenny Army Depot, Chambersburg, Pennsylvania 17201. Contractors should submit such requisitions or requests to their contracting officers.

Comments and suggestions on this handbook are welcome and should be addressed to Army Research Office-Durham, Box CM, Duke Station, Durham, North Carolina 27706.

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CHAPTER 1

HISTORY OF MILITARY PYROTECHNICS

1-1 INTRODUCTION

Pyrotechnics is an old craft that has continued to assume greater military importance. In their simplest form, pyrotechnic devices consist of an oxidizing agent and a fuel that produce an exothermic self-sustaining reaction when heated to ignition temperature. Man's earliest pyrotechnic devices may have been the result of an accidental mixing of saltpeter (KNO_3) with charcoal; or natural tars and resins, animal fats, volcanic dusts, salts, sulfur, or other flammable materials.

In modern warfare, some of the important uses for pyrotechnic devices are: as incendiaries; as luminous sources for missile tracking; as accessories in aircraft, missiles, and nuclear devices; to produce sound signals; and to produce visible luminous and smoke signals. Illuminating devices are also used for photography.[4] Recent adaptations include devices designed for actuation by radio signals directed to a missile thousands of miles from earth.

1-2 EARLY HISTORY[1,2,3,5,6,7]

Incendiary and colored smoke mixtures were used for war, religious celebrations, and entertainment in Arabia, China, Egypt, Greece, and India in very ancient times. As early as 2000 B.C., tales of war in India mention incendiaries, smoke screens, and noxious fumes. Later, against Alexander the Great (365-323 B.C.), defenders of an Indian city were reported able to "shoot thunder and lightning from the walls." To this day natural deposits of saltpeter are abundant in India, and probably served as a source of this material for employment in the compositions making these displays possible.

Knowledge of pyrotechnics traveled from the East to Europe at the beginning of the Christian era. The earliest record of pyrotechnic exhibitions in Europe mentions the Roman Circus during the reign of Augustus (27 B.C. to 14 A.D.). Roman use of pyrotechnics appears to have been largely for display. Movable frameworks were fitted with adjustable parts and designed to set in motion various colored lights.

A military use of pyrotechnics that began early and persisted for many centuries was the use of fire ships in marine warfare. The earliest recorded mention of fire ships is from the 4th century B.C. when the Phoenician seamen of Tyra used them in battle against Alexander the Great. Later records show that the Greeks used them against the Turks, the Crusaders used them at Acre, and the English, in the 16th century, used them with success against the Spanish Armada.

1-2.1 GREEK FIRE

One of the earliest and most successful means of chemical warfare was the mixture known as Greek fire, the use of which is first reported in the 7th century, A.D. This mixture of sulfur, resin, camphor, and other unknown combustible substances, melted with saltpeter, was a powerful incendiary that also produced suffocating fumes. It was used in many different ways. Sometimes woolen cords were soaked in the mixture, dried, and rolled into balls. The balls were then lighted and hurled by large engines at enemy ships or tents. Defenders of cities prepared it in liquid form; poured it into jars; then ignited the mixture and poured it upon those besieging the city walls. In open battles, it was squirted by hand pumps and bellows through pipes into enemy ranks, or against wooden barricades. In 901 A.D. the Saracens were reported to have blown it from pipes mounted on the decks of their ships. Five centuries later, in Emperor Leo's attack on Constantinople in 1453 A.D., 2000 enemy ships were reported destroyed by its use.

1-2.2 CHINESE PYROTECHNICS

Records of Chinese pyrotechnic items go back to the 10th century. Rockets and Roman candles are mentioned in 969 A.D. and, by the 13th century, colored smokes for signaling, incendiary-carrying fire arrows, and rocket-propelled arrows were employed. The rocket-propelled arrows, fired in clusters from metal containers, were sometimes fitted with poisoned razor-sharp heads for attacks from ambush and the defense of defiles. Other Chinese weapons of this time included "flying fire spears" equipped with tubes that threw fire forward for about 30 feet. Pyrotechnic devices were also used in defending cities—the Kin Tarters are known to have used fire powders and other pyrotechnic devices against a Mongol attack in 1232 A.D.

1-2.3 GUNPOWDER

The inventor of gunpowder is generally believed to have been the English philosopher, Friar Roger Bacon. In 1242 A.D. he revealed the ingredients for black powder in defending himself against an accusation of witchcraft. Although Bacon knew of the explosive power of gunpowder, he apparently did not recognize the possibility of using it for projection of missiles.

The earliest recorded use of firearms or of gunpowder as a propellant is in the beginning of the 14th century. Records of the University of Ghent in Belgium indicate that the first gun was invented by Berthold Schwarz in 1313, and commercial records indicate that guns and powder were exported from Ghent to England in the following year. Guns and gunpowder may have been used in the English invasion of Scotland in 1327, but the earliest undisputed record of the use of gunpowder in war is in France at the battle of Crecy in 1346. Gunpowder was also used as an explosive to blast fortification walls, the first reported attempts being at Pisa in 1403, and in land mines, which were described in 1405.

When gunpowder began to be used as a propellant in the 14th to 15th century, the usefulness of the incendiaries then available declined. Because of the use of gunpowder, armies began to engage each other at such distances as to prohibit the use of contact or short range incendiary devices.

1-2.4 MISCELLANEOUS USES

The first recorded use of screening smoke in more recent times occurred in 1701, when Charles XII of Sweden burned damp straw to produce a smoke screen to cover a river crossing. Elsewhere in Europe at this time pyrotechnic devices were being developed for their military value. The French kings encouraged experiments and tests, saw that proper records were kept, of which many are still available, and collected information from travelers returning from other countries. French priests returning from China brought detailed knowledge of the state of the art in that country.[9]

1-3 18TH AND 19TH CENTURIES[2,3,5,6]

Berthollet's discovery of potassium chlorate in 1788 began the modern era in pyrotechnics. Potassium chlorate made color effects in pyrotechnic flames possible and the introduction of magnesium in 1865 and aluminum in 1894 added greatly to the variety of effects attainable.

In Europe there was also a great interest in the use of rockets. Several types were developed, the most successful being the Congreve rocket, which was 30 inches long, 3½ inches in diameter, and carried an incendiary charge. The British used rockets with pyrotechnic compositions in a number of campaigns. A rocket corps was part of the British Army during the Revolutionary War, and again during the War of 1812. The 1805 expedition of Sir Sidney Smith against Boulogne included boats fitted for salvo firing of rockets, and rockets were used successfully in the British attack on Copenhagen and by Wellington's army.

In the United States at this time, a number of pyrotechnic devices were items of general ammunition issue. An 1849 Ordnance manual describes signals, lights, torches, tarred links, pitched fascines, incendiary matches, and other illumination devices. The manual also lists firestone, Valenciennes composition, and fireballs—incendiaries, when projected from mortars, designed to set fire to enemy property. Besides the Congreve rocket, which came in 2¼- and 3¼-inch sizes. The

2¼-inch rocket had a maximum range of 1760 yards and the 3¼-inch rocket had a somewhat greater range. The rockets were made of sheet or cast iron and fired from tubes mounted on portable stands or light carriages. An 1861 Ordnance manual lists most of the 1849 devices with more detail and some improvements. Two new items were also listed: an incendiary projectile filling called rockfire, which burned slowly and was hard to extinguish. It was employed to set fire to buildings, ships, and flammable stores. Another new device was the petard, a powder-filled wooden box that was used to demolish doors, gates, barriers, and other obstacles.

A number of gunpowder improvements were made in the United States and Europe during the latter half of the 19th century. After General Thomas J. Rodman, U.S. Army, discovered the principle of the progressive burning of propellant powder in 1860, powder grains were made in sizes adapted to the caliber of gun, with larger and perforated grains used in larger weapons. The Swedish inventor, Nobel, made many of his important discoveries at this time. In 1863 he first manufactured nitroglycerin commercially, and during the next twenty years invented dynamite, the fulminate blasting cap, blasting gelatin, gelatin dynamite, and ballistite. Another improvement came in 1886 when Vieille, a French chemist, discovered the means to colloid nitrocellulose and thus control the grain size of the propellant powder.

1-4 EARLY 20TH CENTURY[2,3,5,6,7,8,9,10]

An important pyrotechnic development early in this century was the tracer bullet. Tracers have been used in all types of projectiles, but their development has been most closely connected with ammunition for automatic small arms. Tracers were the best devices for directing automatic small arms fire against fast moving ground targets. In this country, research and development of small arms tracers was carried out at Frankford Arsenal. The U. S. Navy and Picatinny Arsenal also conducted tracer development for 20 mm, 40 mm, and larger guns.

The German Navy conducted fleet maneuvers using chemically produced screening smoke for the first time in 1906, and later used such smoke screens with success at the Battle of Jutland in 1916. As a result of this success, the Allies and the Germans developed pyrotechnic screening smoke for use on both land and sea during World War I.

1-4.1 WORLD WAR I

During World War I, opposing troops in trenches separated by short distances regularly employed pyrotechnic devices. Illuminating projectiles were used as protection against surprise attack, and signals were used to request, adjust, or stop artillery fire; to mark enemy and friendly troop locations; and for emergencies on land, sea, and in the air.

The advent of the airplane overcame the difficulties of using incendiaries against distant armies. Forerunners of today's incendiary bombs were first dropped on London in May 1915 from German Zeppelins, and a prototype of the portable flamethrower was used by the Germans against the French in April and June of that year, although with little success. Later in the war, bombs containing white phosphorus, thermite, and thickened liquid fuels were dropped from airplanes.

Before and during World War I most pyrotechnic development and manufacturing in the United States was carried out by private contractors to the Army or Navy. The Star rifle light, the Very pistol, position lights, and simple rockets were the main items used. As the war continued, the armed services began to test and develop pyrotechnic devices for special purposes.

The use of chemical agents during the war resulted in the establishment of a Chemical Warfare Service in 1918. This organization became a permanent branch of the U.S. Army in 1920, and in 1946 its name was changed to the U.S. Army Chemical Corps. This technical service pursued the development of incendiaries, screening and signaling smokes, flame throwers, and toxic chemical compounds.

Aberdeen Proving Ground in Maryland was activated in October 1917, and by December of that year was making acceptance tests of ammunition and other Ordnance materiel. Aberdeen records for 1918 list tests of illuminating parachute projectiles for the 155mm gun.

Frankford Arsenal, during the early days of

the war, adapted foreign pyrotechnic compositions to small arms ammunition. Later, it developed tracer and igniter compositions and started a well-integrated program for standardization. These early tracer compositions were made by a small batch process, wet mixed, dried, and ground to produce a stable, uniform composition. These early compositions were only moderately satisfactory in that the calomel used as a flame brightener produced season cracking in brass, and also limited the life of the composition.

During the war the Navy developed and used 3-, 4-, 5-, and 6-inch illuminating projectiles with a projection range up to 7 miles, a major advantage because the Star rifle light was projected to a maximum range of only 800 yards. The Navy also developed water markers for use from submarines, as well as for dropping from aircraft. These markers consisted of surface burning smoke and flame-producing items, colored aerial stars, and surface marking dyes.

1-4.2 BETWEEN THE WARS

During the period between World War I and World War II, arsenals, such as Picatinny and Frankford, and the Army Chemical Corps carried on limited research on military applications of pyrotechnics. Some universities also assisted in this work.

Picatinny Arsenal, which had been established by the Ordnance Corps in 1879 as a small powder depot to manufacture and load munitions, began loading propellant charges in 1896, projectiles in 1902, and propellant manufacture in 1907. In 1919, it began to develop and manufacture pyrotechnic signals, and continued the pyrotechnic research and development effort in the period between the wars. During this time, it made considerable progress in developing new smoke, flare, tracer, and delay compositions, and began to accumulate evidence regarding the necessity for purer ingredients, more careful control of particle size, and improved processing methods. Other investigations produced techniques to measure luminosity and color of pyrotechnic flames, technical requirements for specifying ingredients, and recognition of the importance of avoiding moisture in pyrotechnic compositions. Although there had been little scientific testing of pyrotechnic devices, the body of data that existed at Picatinny Arsenal at the outbreak of WW II was of considerable value in developing improved pyrotechnic items needed for the highly mobile forces of that war.

Aberdeen Proving Ground added development testing to its proof testing in the 1920's. In 1921 development tests were reported on green, yellow, and white smokes, and two years later tests of long burning white parachute signals were conducted.

About 1933, Frankford Arsenal refined the process of making tracer compositions so that only the calcium resinate and the hygroscopic strontium peroxide were wet mixed. Since then, streamlining of the process has continued and now all ingredients in the tracer mix are purchased in the required granulation, blended dry, and charged into bullet cavities under high pressures. In 1936 Frankford began developing delay action and dim igniters, some of which are now standard compositions. Just before the United States entered World War II, Frankford greatly improved incendiary mixture IM-11. This standard incendiary mixture, which was originally developed by Picatinny Arsenal, was quickly adopted by the British and was used by American forces in all small arms incendiary bullets during World War II.

The Navy pyrotechnic development between the wars was centered at the U.S. Navy Yard in Washington, D. C. Production was carried out at the Naval Ordnance Plant at Baldwin, New York. For a time its one product was illuminating projectiles, but in 1930 production of aircraft parachute flares was also added. Also, by 1933 the Experimental Ammunition Unit of the Naval Gun Factory had developed a number of pyrotechnic items including emergency identification signals, aircraft signal cartridges, and ammunition tracers.

1-4.3 WORLD WAR II

In 1940, and later with the entry of the United States into World War II, pyrotechnic items such as flares, illuminating projectiles, smoke signals, spotting charges, many types of ground and aircraft signals, and incendiaries were needed in enormous quantities.

Flares were widely used to illuminate landing

fields at night, in rain, and in fog. They were dropped from aircraft to illuminate enemy territory; to silhouette ships for observation; and to locate targets for bombing. Photoflash bombs illuminated large areas for night photography.

Smoke screens were used by land and sea forces for a variety of purposes: aircraft and smoke boats screened ships during air attacks and amphibious landings, concealed underwater demolition teams and tactical maneuvers of ground troops.

By the end of the war pyrotechnics provided visual communication both day and night between planes and tanks, tanks and artillery, infantry and aircraft, and ships and the shore.

Incendiary bullets, bombs, projectiles, and grenades were widely used in Europe. Allied tactics in bombing German cities employed equal quantities of incendiaries and high explosives. On a weight basis, the incendiary bombs caused five times more damage than high explosive bombs. The central parts of more than 50 of Germany's largest cities were leveled by fire. Before nuclear weapons were used fifty percent of 70 Japanese cities had been burned. More than 99 percent of the total bomb load dropped on Japanese cities was incendiary, with less than 1 percent high explosive. During the war, hundreds of millions of incendiary bombs, projectiles, and grenades were provided by the Chemical Warfare Service—over 48 million incendiary bombs alone were supplied to the U.S. Army Air Force.

Flame throwers, which had been developed during World War I, were improved and used with success in the campaigns in the Pacific areas during World War II.

Picatinny Arsenal developed many improved pyrotechnic items to meet the military change from trench warfare, which had existed in World War I, to the highly specialized mobile forces of World War II. Pyrotechnic ammunition for military maneuvers and means for providing visual communication among the various elements involved were essential. More efficient flares, flash charges, and a variety of spotting charges, signals, tracers, and troop warning devices were developed to meet the new tactical requirements. New ingredients such as atomized magnesium, resins, color intensifiers, and others were tested and adopted; improved techniques to measure luminosity and color, such as the barrier-layer cell photometer, were introduced.

The Ballistic Research Laboratories had been established in 1938 to centralize research activities at Aberdeen Proving Ground and to undertake research in fundamental Ordnance problems. With completion of a new laboratory in 1941, basic studies were begun in areas pertinent to pyrotechnics such as flame propagation, burning rates, sensitivity of pyrotechnic compounds, and the physical chemistry of gases.

Naval pyrotechnics development during World War II was centered at the Naval Ordnance Laboratory, then located at the Naval Gun Factory, Washington, D. C., and production was centered at the Naval Ammunition Depot, Crane, Indiana. The Navy improved existing items for greater reliability and storage characteristics, and developed such items as chemical delay powders, self-releasing buoyant submarine signals, rescue flares, depth charge markers, aircraft signal cartridges, and parachute flares.

1-5 POST WORLD WAR II PERIOD[4,12]

Funds for research and development of pyrotechnic items were limited in the period following World War II; however, significant advances were accomplished which made available improved pyrotechnic devices, signals, smokes, incendiaries, and battlefield illuminants when the Korean Conflict developed in the early 1950's.

Most pyrotechnic research and development today is carried out by the Government at Picatinny Arsenal, Aberdeen Proving Ground, Frankford Arsenal, the Army Chemical R&D Laboratories, the Naval Ordnance Laboratory, the Naval Ordnance Test Station, the Naval Ammunition Depot, and by Government-sponsored agencies.

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CHAPTER 2

INTRODUCTION TO MILITARY PYROTECHNICS

2-1 INTRODUCTION

Modern military pyrotechnics as an outgrowth of "Greek Fire" and the "art of making fireworks" has progressed to the extent where pyrotechnic devices and systems in both offensive and defensive military operations have become indispensable. It has developed into a science requiring extensive and intensive basic and applied research to meet new conventional and unique military and space requirements.

The early modest state of progress was changed considerably, however, when military operations became mechanized with the development of the tank, the bombing plane, the submarine, long-range artillery, the aircraft carrier, other vehicles, and weapons; and the introduction of combined operations. To coordinate all these forces and to provide for visual communications between plane and tank, tank and artillery, infantry and air force, both day and night, the development of pyrotechnic ammunition for these purposes was absolutely essential. Increased use of aircraft for bombing and observation purposes required the use of flares and photoflash bombs which could be released from rapidly moving planes to illuminate enemy territory for night photography and observation and to locate targets for bombing.

A variety of smoke signals, spotting charges, bombardment flares, illuminating shells, ground and aircraft signals had to be developed to satisfy new tactical requirements. New demands for signaling capability required the development of improved colored smokes and signals.

For submarine identification and air-sea rescue operations, sea water activated, battery-operated, floating marking signals were developed with good life and stability. Many types of simulators for land and sea troop training were also developed and became an indispensable aid in these operations.

With the advent of the space age, pyrotechnic devices have become increasingly important. They are used extensively for spotting and tracking rockets and missiles, for recovery operations, and for special purpose countermeasures. To meet the requirements for these applications, it has been necessary to investigate pyrotechnic reactions under conditions of low pressure, low temperature, greatly reduced quantities of atmospheric oxygen, varied degrees of confinement, and with different types of initiating systems.

Basic studies have been undertaken to attain a fundamental understanding of the preignition, ignition, and self-propagative reactions of pyrotechnic ingredients. Theories have been developed which are used as a guide for formulating flame compositions burning cigarette-fashion, with specific burning rate requirements. Theoretical and empirical relationships have been developed to predict the rates of propagative burning of slow-burning pyrotechnics as a function of particle size and composition. Instrumentation has been developed to evaluate luminous intensity and colors of pyrotechnic flames, luminous intensity and duration of flashes, color of smoke clouds, and improved output of pyrotechnic flares. Laboratory studies include use of thermal analytical techniques, spectrophotometric and chromatographic analyses.

To continue to meet new challenges, principles and theories of engineering and science must be exploited and put to practice. Only when this is done will it be possible to elucidate reaction mechanisms, performance of pyrotechnic devices and to develop superior compositions and items.[1,2,3,4,5,8]

2-1.1 PYROTECHNIC DEVICES AND USES[1,2,6,7,9,10]

The terminal effect of military pyrotechnic items such as light, heat, smoke or sound results from an exothermic oxidation—reduced chemical

TABLE 2-1
TABULATION OF PYROTECHNIC DEVICES

1. *Flares*
   a. Reconnaissance
   b. Observation
   c. Bombardment
   d. Deplaning and emplaning of troops and materiel
   e. Prevention of enemy infiltration or reconnaissance
   f. Target identification
   g. Battlefield illumination
   h. Marking targets and bomb release lines
   i. Emergency airstrip location and identification
   j. Decoys
   k. Missile tracking
2. *Signals*
   a. Between various elements of ground troops
   b. Between ground troops and planes, or vice versa
   c. Between planes in the air
   d. Search and rescue operations (locate survivors)
   e. Submarine to surface or air
   f. Precision location of point or time in space for assessment of missile function
   g. Establishment of points on a trajectory
3. *Colored and White Smokes*
   a. For daytime signaling
   b. For screening
   c. For spotting
   d. For marking targets
   e. Thermal attenuating screen
   f. Dissemination of chemical agents
   g. Tracking and acquisition
   h. Rescue
4. *Tracers*
   a. To trace trajectories of projectiles or rockets
   b. For self-destruction of ammunition after a definite time interval
5. *Incendiaries*
   a. For use against ground targets
   b. For use against aircraft targets
   c. For emergency document and equipment destruction
6. *Pyrotechnic Delays*
   Time delay for explosive trains
7. *Photoflash Bombs and Cartridges*
   Aerial night photography
8. *Spotting and Tracking*

TABLE 2-1 (cont'd)

9.	*Atmosphere and Space Studies*
10.	*Simulated Ammunition for Troop Training*
11.	*Rocket Igniters*
12.	*Fuel Igniters for Ramjet Engines and Guided Missiles*
13.	*Aircraft Engine Igniters*
14.	*Water Markers*
15.	*Heat Sources*
16.	*Special Devices*

reaction within a mixture of a fuel and an oxidant. Additives or modifiers may be included to produce more saturated colored flames, to adjust burning rates, to produce colored smoke clouds, and to increase storage life and processing safety.

Pyrotechnic devices are employed in such a large variety of munitions that classification is difficult. These devices are, however, tabulated, with their principal uses, in Table 2-1.

2-1.2 CHARACTERISTICS OF PYROTECHNIC COMPOSITIONS[1,2,4,6,7]

The applicability of a specific pyrotechnic mixture for a particular application is governed by many "yardsticks." Consideration must be given, not only to the terminal effectiveness and output desired, but also to overall performance and reproducibility, and processing and storage characteristics. Precise and analytical determination of the various parameters involved requires continued research to develop improved evaluative methods.

The more important characteristics of pyrotechnic compositions used for military purposes may be stated as follows:

2-1.2.1 Performance Characteristics

a. Heat of reaction. cal/gm or cal/cc. May be used as a basic criterion for selection of fuel-oxidizer combinations.

b. Burning rate. inches/second, inches per minute, seconds/inch. Applied to consolidated mixtures and measured as a linear rate.

c. Luminous intensity. candela or candlepower. Visible output or illumination in candela.

d. Color value. The color quality of a colored pyrotechnic flame taken as the ratio of the apparent luminous intensity through an appropriate colored filter to the total luminous intensity.

e. Visibility. Applied to illuminating and signal devices; measured in terms of brightness and other qualities.

f. Efficiency. Relates the output to the original weight or volume of compositions; for illuminating or signaling it is expressed as candle/seconds per gram or per milliliter; for smoke-producing devices efficiency is considered to be the percent of chemical vaporized based either on the weight of chemical originally contained or on the total weight of munition, depending on the requirements of the evaluator.

g. Color and volume of smoke. Compared to standard charts or by observers' ability to detect and recognize, at prescribed distances, the color and the total obscuring power (TOP).

2-1.2.2 Processing and Sensitivity Characteristics

Information on the processing, storage, shipping, and sensitivity characteristics of pyrotechnic compositions can be found in Part Two of this series, AMCP 706-186.

2-1.2.3 General Functioning Characteristics

a. Ignitibility. The ease with which a pyrotechnic composition ignites, determined by standard time-to-ignition tests described in Part Two of this series, AMCP 706-186.

b. Hygroscopicity. The ease with which a composition picks up moisture at a preselected temperature and relative humidity.

c. Reaction characteristics. Fundamentally important are the heat of reaction and rate of reaction of a pyrotechnic composition. To make a consolidated composition burn propagatively, sufficient heat must be evolved and the rate of reaction must

be of sufficient magnitude to more than compensate for heat losses.

In addition to the heat of reaction and the rate of reaction, display characteristics are influenced by many other factors. Some of the more important include:

1. Granulation or particle size of ingredients
2. Composition of ingredients
3. Purity of ingredients
4. Burning surface area
5. Heat transfer characteristics
6. Flare case material and configuration
7. Loading pressure
8. Presence of moisture
9. Degree of confinement
10. Ambient temperature and pressure
11. Method of ignition
12. Length-to-diameter ratio
13. Method and energy of dissemination
14. Bomb burster geometry
15. Velocity, acceleration and aerodynamics of device

The importance of a particular influential factor may vary considerably with the application. Factors such as the average particle diameter, specific surface, shape, and distribution will affect the burning rate of consolidated pyrotechnic mixtures. Changes in the general characteristics of the flare case and the area of the burning surface combine to influence the output of flame producing items. With pyrotechnic delay compositions, the burning rate is of primary significance and may be varied by changes in the percentages and particle size of the ingredients in the composition, incorporating additives, varying the compaction, and by other means. Nonconsolidated pyrotechnic photoflash mixtures used in flash items are influenced by the method of ignition, ratio of length to diameter, burster geometry, and degree of confinement.

In addition, there are many other factors peculiar to the specific item under consideration that may exert varying influences on performance. In the design and development of new pyrotechnic munitions, a fresh approach should always be considered, using the data available on existing devices only as a guideline.

2-1.3 Constituents in Pyrotechnic Compositions[1,2,4,6,7]

The constituents upon which the performance of pyrotechnic compositions and devices is dependent include a basic fuel and oxidizer combination with other ingredients. These may consist of dyes, color intensifiers, retardants, binding agents, water-proofing agents, and substances to create a specific effect.

Typical ingredients in each of these categories are:

1. Oxidizing Agents. Nitrates, perchlorates, peroxides, oxides, chromates and chlorates. These are all substances in which oxygen is available at the high temperatures of the chemical reaction involved. In addition, fluorinating agents such as Teflon and Kel-F are finding use as oxidizing agents.

2. Fuels. Metal powders, metal hydrides, red phosphorus, sulfur, charcoal, boron, silicon, silicides. When these substances are finely powdered, they readily undergo an exothermal oxidation with the formation of corresponding oxides and the evolution of heat and radiant energy.

3. Color Intensifiers. Highly chlorinated organic compounds, such as hexachloroethane (C_2Cl_6), hexachlorobenzene (C_6Cl_6), polyvinylchloride, and dechlorane ($C_{10}Cl_{12}$). These compounds are utilized to produce specific spectral emitters in pyrotechnic flames.

4. Retardants. Inorganic salts, plastics, resins, waxes, oils. These are used to slow down the reactions between the oxidizing agent and the powdered metal to produce the desired burning rate. Some behave merely as inert diluents while others participate in the reaction at a much slower rate than the main constituents.

5. Binding Agents. Resins, waxes, plastics, oils. These are added to prevent segregation and to obtain more uniformly blended compositions. In addition, they serve to make finely-divided particles adhere to each other when compressed into pyrotechnic items and help to obtain maximum density and burning efficiency. Binders also frequently desensitize mixtures which are otherwise sensitive to impact, friction and static electricity.

6. Waterproofing Agents. Resins, waxes, plastics, oils, dichromating solutions. These are used

TABLE 2-2
COMPARISON OF SOME PROPERTIES OF PYROTECHNIC COMPOSITIONS WITH EXPLOSIVES

Composition	%	Cal/gram	Noncondensable Gas Volume, cc/gram	Brisance, Grams Sand Crushed	Ignition Temp*, °C	Impact BM**, Cm	Impact PA***, in.
PYROTECHNIC:							
Delay							
Barium chromate	90						
Boron	10	480	13	0	650	—	12
Delay							
Barium chromate	60						
Zirconium-nickel alloy	26						
Potassium perchlorate	14	497	12	0	485	56	23
Flare							
Sodium nitrate	38						
Magnesium	50						
Laminac	5	1456	74	8	640	60	19
Smoke							
Zinc	69						
Potassium perchlorate	19						
Hexachlorobenzene	12	616	62	8	475	23	15
Photoflash							
Barium nitrate	30						
Aluminum	40						
Potassium perchlorate	30	2147	15	7	700	100	26
HIGH EXPLOSIVE:							
TNT		1060	1000	48	475	100	14
RDX		1240	600	60	260	13	5
BLACK POWDER		684	272	8	288	32	16

* 5-second value ** Bureau of Mines *** Picatinny Arsenal

as protective coatings on metals such as magnesium, aluminum and zirconium-nickel alloys to reduce their reaction to atmospheric moisture.

7. Dyes for Smokes. Azo and anthraquinone dyes. These dyes provide the color for smokes used for signaling, marking, and spotting.

Many of the above substances perform more than one function, thus simplifying the composition of some pyrotechnic mixtures.

2-1.4 Comparison of Pyrotechnic Mixtures and Explosives[1,2,6,10]

Pyrotechnic mixtures can be devised to produce as little as 200 calories per gram of mixture or in

excess of 2000 calories per gram. Reaction temperatures exceed 3000°K in some cases.

Such amounts of energy and the high temperatures attained can be extremely dangerous. In general, because the quantity of gas produced is less, and the release of energy is at a lower rate, the terminal effects produced by pyrotechnic compositions are less severe than those produced by high explosives.

A comparison of some of the more important properties of pyrotechnic compositions and explosives is given in Table 2-2. As indicated in this table, pyrotechnic compositions, in general, are not as sensitive to heat as explosives. Impact values listed indicate that some pyrotechnic compositions are at least as sensitive to shock as explosives.

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CHAPTER 3

PHYSICAL-CHEMICAL RELATIONSHIPS

The output characteristics of a pyrotechnic munition are determined, to a large extent, by the temperatures to which the reaction products are heated as a result of the chemical reaction between the fuel and oxidizer. The maximum temperature of the reaction products depends on: (1) the state of the products at the reaction temperature, (2) the heat evolved by the exothermal chemical reaction, and (3) the rate of heat production and heat loss. Physical-chemical relationships allow the state of the products, the energy released, and the maximum reaction temperature to be calculated. The rate of heat production and heat loss, which are influenced by the ambient temperature and pressure, confinement, and many other inter-related factors, can also be calculated for certain simple cases. However, for most reactions, these quantities must be determined experimentally.

The physical-chemical relationships which are applicable to pyrotechnics are summarized in this chapter, and pertinent examples are given to illustrate their application.

3-1 STATE OF A SYSTEM

The state of any system (gas, liquid, or solid) can be described by specifying a sufficient number of its properties such as mass, volume, temperature, and pressure. These properties are classified as: (1) extensive properties which depend on the size of the system, and (2) intensive properties which are independent of the size of the system. It is unnecessary to specify all the properties of a system in order to characterize its state; two independent variables, commonly the intensive variables of pressure and temperature, are sufficient for a given amount of pure substance. A mathematical expression for this relationship is an equation of state which, for one mole of a pure substance with volume as the dependent variable, has the form:

$$V = f(T, p) \tag{3-1}$$

Similar expressions can be written with T and p as the dependent variable. If a system has n components, n-1 composition variables must be specified.

3-1.1 THE GASEOUS STATE

The gaseous state is characterized by changes in volume with changes in temperature and pressure. Gases normally have no bounding surface and, therefore, tend to completely fill any available space. A knowledge of the behavior of gases with changes in temperature and pressure is essential because of the importance of the gaseous state at the high temperatures involved in pyrochemical reactions.

Gaseous products formed in the combustion of many pyrotechnic mixtures may range from essentially zero, for most thermites and some types of delay mixtures, to 15 to 20 percent for light-producing compositions, to 50 percent for some smoke-producing mixtures. At the high temperatures produced by the burning of pyrotechnic compositions, many substances not usually considered gaseous will exist in the gaseous state. The formation of gas, both as a permanent product and as an intermediate product which exists only during the reaction, is indicated in light-producing mixtures by the presence of a flame. Gaseous combustion products are necessary in smoke-producing mixtures to aid in the formation of dispersed, particulate matter and to carry this matter into the atmosphere.

3-1.1.1 Ideal Gases

The behavior of gases at low pressures and high temperatures is often approximated by an equation of state known as the ideal gas law:

$$pv = nRT = \frac{W}{M}RT \tag{3-2}$$

where p is the pressure, v is the volume, n is the

number of moles, R is the universal gas constant, T is the absolute temperature, W is the weight of gas, and M is the molecular weight of the gas, using any set of consistent units. The density d of an ideal gas at various temperatures and pressures is:

$$d = \frac{W}{v} = \frac{pM}{RT} \qquad (3\text{-}3)$$

The ideal gas law applies, strictly, to a hypothetical gas, which is composed of mass points between which no forces are acting. At the high temperatures and relatively low pressures produced by burning unconfined pyrotechnic compositions, the ideal gas law is fairly accurate. At the higher pressures which may be produced when a confined pyrotechnic composition is burned, the behavior may deviate appreciably from that of an ideal gas.

3-1.1.2 The Universal Gas Constant and Standard Conditions

It has been determined that one mole of an ideal gas occupies 22.414 liters at 273.16°K and one atmosphere. Then, from Equation 3-2:

$$R = \frac{pv}{T} = \frac{(1)(22.414)}{(273.16)} = 0.08205 \frac{\text{liter-atm}}{\text{°K mole}} \qquad (3\text{-}4)$$

The universal gas constant R has the units of energy per degree-per mole. It may be calculated from Equation 3-4 for one mole of gas at standard conditions. The value of R must be consistent with the units of pressure, temperature, and volume used in the ideal gas law. Some values of R include:

Value	*Units*
0.08205	$\frac{\text{liter atmospheres}}{\text{gram mole degree Kelvin}}$
10.73	$\frac{\text{psia cubic feet}}{\text{pound mole degree Rankine}}$
1.987	$\frac{\text{calories}}{\text{gram mole degree Kelvin}}$
1.987	$\frac{\text{BTU}}{\text{pound mole degree Rankine}}$

In some references, including many of those dealing with rocke propulsion, a gas constant R' may be given in weight units of a particular gas instead of in moles. In this case:

$$R' = \frac{R}{M} \qquad (3\text{-}5)$$

where M is the molecular weight of the gas, and R is the universal gas constant.

3-1.1.3 Real Gases

In a real gas, the forces acting between the molecules as well as the volume of the molecules cause deviations from ideal behavior. Several equations of state have been proposed to more closely approximate the behavior of real gases. Some of these equations of state include:

Van der Waal's Equation:

$$\left(p + \frac{n^2a}{V^2}\right)(v - nb) = nRT \qquad (3\text{-}6)$$

where a is a correction for the forces between molecules of a real gas, and b, termed the co-volume, is a correction for the volume of the molecule. The units used for a and b must be consistent with those used for the other variables.

Abel's Equation:

$$(p)(v - nb) = nRT \qquad (3\text{-}7)$$

where b is the correction for the volume of the molecules. This equation, which is a modification of *Van der Waal's Equation*, applicable where the pressure is high, has been quite widely used for calculations involving explosives and propellants.

Virial Equation:

$$pv = nRT\left(1 + \frac{B}{v} + \frac{C}{v^2} + \cdots\right) \qquad (3\text{-}8)$$

where the coefficients B, C, etc., vary with temperature and are called the second, third, etc., virial coefficients. This particular equation is a very general equation of state for real gases. By using enough terms, the values calculated from the above equation can be made to agree with experimental data as closely as desired.

Compressibility Factor

The deviation of a gas from ideal behavior can also be expressed by the use of a compressibility factor K where:

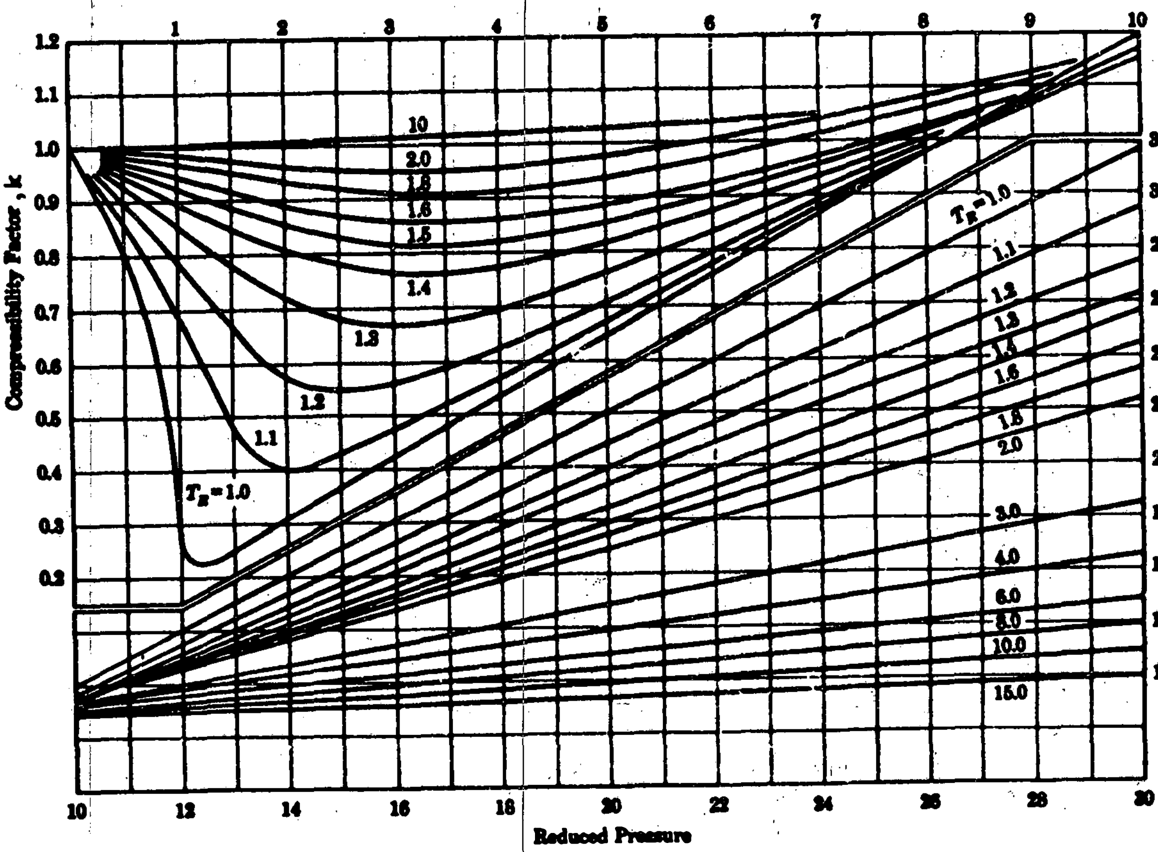

Figure 3-1. Compressibility Factors as a Function of Reduced Pressure

$$K = \frac{pv}{nRT} \quad (3\text{-}9)$$

or, in terms of reduced variables:

$$K = (\text{Constant}) \left(\frac{p_r V_r}{T_r}\right) \quad (3\text{-}10)$$

in which a reduced variable is the variable divided by its value at the critical point, i.e.:

$$p_r = (p/p_c),\ T_r = (T/T_c),\ \text{and}\ V_r = V/V_c \quad (3\text{-}11)$$

The critical point is defined when the properties of a liquid and gas phase which are in equilibrium become identical. The p, v, and T quantities, associated with this critical point, are defined as p_c, v_c, and T_c. Therefore, as predicted by the law of corresponding states, if K is plotted against p_r at a given T_r, a single curve will result for all gases as shown in Figure 3-1. The compressibility factor estimated from these curves allows a value for any one of the three variables p, v, and T to be calculated in terms of the other variables with a fair degree of accuracy. The compressibility factor can be determined experimentally or by calculation using a suitable equation of state.

3-1.1.4 Gas Mixtures

Gas mixtures are normally treated by Dalton's Law, i.e.,

$$p_{total} = p_1 + p_2 + \cdots = \sum_{i=1}^{n} p_i \quad (3\text{-}12)$$

where the partial pressure p_i of each of the components is defined as the pressure which would be exerted if it occupied the total volume at the same temperature. Gas mixtures can also be treated by the Amagat additive volume law:

$$v_{total} = v_1 + v_2 + \cdots = \sum_{i=1}^{n} v_i \quad (3\text{-}13)$$

where the volumes of the individual components v_1, v_2, etc., are the volume each would occupy at the (total) pressure and temperature of the mixture. For ideal gas mixtures, the results obtained with this equation will be the same as those obtained by use of the additive pressure law. The application of both of these laws to real gas mixtures is somewhat more difficult.[1]

3-1.1.5 Sample Calculations

Example One: Analysis of the product gases produced by a burning fuel block composition, containing ammonium nitrate and charcoal, indicates that the reaction taking place could be represented by the overall reaction:

$$6NH_4NO_3(s) + 4C(s) \rightarrow 11H_2O(g) + CO(g) + 3CO_2(g) + 6N_2(g) + H_2(g)$$

(a) The volume of gas produced per gram of mixture burned at standard temperature and pressure can be calculated from the above reaction and the ideal gas law. The reaction produces 22 moles of product gases from 6 moles of NH_4NO_3 (480 grams) plus 4 moles of charcoal (48 grams) or a total of 528 grams of fuel block.

Moles of gas per gram of fuel block burned:

$$\frac{22}{528} = 0.041 \text{ moles per gram}$$

Volume of gas produced (STP) per gram of fuel block burned is:

$$V = \frac{nRT}{p} = \frac{(0.041)(0.082)(273)}{1}$$
$$= 0.918 \text{ liters per gram}$$

(b) Since the actual temperature of the product gases is 1000°C, the calculated volume at this temperature and one atmosphere would be considerably greater:

$$V_{1000^\circ C} = \frac{1273}{273}(0.918) = 4.28 \text{ liters per gram}$$

(c) The partial pressure of one of the gaseous products may be found by using the ideal gas law and moles of the component desired and the total volume for n and V. The partial pressure of carbon dioxide would be calculated as follows:

$$P_{CO_2} = \frac{n_{CO_2}RT}{V_{total}} = \frac{(3/528)(0.082)(273)}{0.918}$$
$$= 0.14 \text{ atmosphere}$$

Since the partial pressure is proportional to the mole fraction of each gaseous component, a simpler method would be:

$$P_{CO_2} = \frac{\text{Moles}_{CO_2}}{\text{Moles}_{total}}(P_{total})$$
$$= 3/22\ (1) = 0.14 \text{ atmosphere}$$

Example Two: A cylinder having a volume of one liter is pressurized to 200 atmospheres with carbon dioxide at a temperature of 40°C. The amount of carbon dioxide can be calculated by:

(a) Assuming carbon dioxide behaves as an ideal gas:

$$v = \frac{pvM}{RT} = \frac{(200)(1)(44)}{(0.082)(313)} = 343 \text{ grams}$$

(b) Assuming that carbon dioxide behaves as a Van der Waal's gas:

$$\left[p + \frac{\left(\frac{w}{M}\right)^2 a}{v^2}\right]\left[v - \left(\frac{w}{M}\right) b\right] = \frac{w}{M} RT$$

For CO_2, $a = 3.59$ liters^2 atm mole^{-2}; $b = 0.0427$ liter mole^{-1}

$$\left[200 + \frac{\left(\frac{w}{44}\right)^2 (3.59)}{(1)^2}\right]\left[1 - \left(\frac{w}{44}\right)(0.0427)\right]$$
$$= \frac{w}{44}(0.082)(313)$$

Solving cubic equation in w: $w = 625$ grams

(c) Use of the generalized compressibility chart, Figure 3-1:

Critical pressure carbon dioxide = 72.9 atmospheres

Critical temperature carbon dioxide = 304.2°K

$$p_r = \frac{200}{72.9} = 2.75$$

$$T_r = \frac{313}{304.2} = 1.03$$

From Figure 3-1, $K = 0.42$

$$w = \frac{pvM}{KRT} = \frac{(200)(1)(44)}{(0.42)(0.082)(313)} = 608 \text{ grams}$$

The experimentally determined value is 835 grams.

3-1.2 THE LIQUID STATE

A liquid, like a gas, has no definite shape and, hence, takes the shape of the vessel in which it is placed. The surface of a liquid, in the absence of other forces, will tend to contract to a minimum area and is responsible for many of its characteristic properties. The molecules of a liquid are less mobile than those in gases but more mobile than those in solids.

In pyrotechnic reactions, liquids are formed by the melting of solids and condensation of vapors. Liquid fuels must be vaporized before sustained combustion will take place. The burning of many solid fuels, including most of the metal fuels, involves the formation and vaporization of a liquid phase as a step in the combustion process.

3-1.2.1 Vapor Pressure

The pressure exerted by a vapor, in equilibrium with a liquid, is the vapor pressure of the liquid. The vapor pressure increases with temperature until the critical temperature is reached above which the liquid cannot exist. The vapor pressure at the critical temperature is termed the critical pressure. The increase in vapor pressure with temperature can be approximated by the empirical equation:[2]

$$\log p = \frac{-0.05223a}{T} + b \tag{3-14}$$

where p is the vapor pressure in milimeters of mercury, T is the absolute temperature °K, and a and b are empirically determined constants for each liquid. For example, aluminum oxide in the temperature range 1840°C to 2200°C has constants of 540,000 and 14.22 for a and b, respectively. At 2100°C, the vapor pressure of the liquid would be:

$$\log p = \frac{-0.05223\ (540{,}000)}{2373} + 14.22$$

$$\log p = 2.32$$

$$p = 210 \text{ mm mercury}$$

The vapor pressure of small droplets, such as mist droplets, is higher than the bulk vapor pressure. If p_o is the bulk vapor pressure of the liquid, the vapor pressure of a droplet p is given by:

$$p = p_o\left(1 + \frac{2\gamma M}{rd\ RT}\right) \tag{3-15}$$

where γ is the surface tension, M is the molecular weight, d is the density of the liquid, r is the radius of the drop, R is the universal gas constant, and T is the absolute temperature.

3-1.2.2 Boiling Point

The temperature at which the equilibrium vapor pressure of a liquid equals the ambient pressure on the surface of the liquid is known as the boiling point. If the ambient pressure is one atmosphere, the temperature at which the liquid boils is termed the normal boiling point. For many liquids, the normal boiling point is approximately two-thirds of the critical temperature. According to Trouton's Rule, the number of calories required to vaporize one mole of many liquids, including some of the metals, is about twenty-one times its normal boiling temperature (degrees Kelvin). By use of Trouton's Rule, the heat of vaporization of some of the metal fuels can be approximated if the boiling temperature is known.[3]

Lithium has a boiling point of 1331°C (1604°K) and its reported heat of vaporization is 32,190 calories per mole. Applying Trouton's Rule:

$$\Delta H_{vap} = 1604(21) = 33{,}700 \text{ calories per mole}$$

3-1.3 THE SOLID STATE

Solids have a fixed shape and volume with the individual units (atoms, molecules or ions) so firmly bound together that there is little freedom for translational motion. Crystalline solids exhibit orderly internal arrangements and exhibit a sharp melting point. Crystals whose properties are different along different axes of the crystal are called anisotropic; if the properties are the same, they are called isotropic. Amorphous solids (such as

glass) may be regarded as super-cooled liquids of high viscosity. They have indefinite melting points and undefined internal arrangements.

The properties of solids are important to the study of pyrochemical reactions, which involve solid ingredients reacting to produce mainly solid products. Intermediate steps in the reaction involve liquid and gaseous phases; however, some pyrochemical reactions may proceed by a solid-solid reaction mechanism.

There are 230 possible crystal forms which can be grouped into 32 classes which, in turn, can be referred to one of the following six crystal systems:

1. Cubic. Three axes of equal length intersecting each other at right angles.
2. Tetragonal. Three axes intersecting each other at right angles with only two of the axes equal in length.
3. Hexagonal. Three axes of equal length in a single plane intersecting at 60° angles, and a fourth axis of different length and perpendicular to the plane of the other three.
4. Rhombic. Three axes of unequal length intersecting at right angles.
5. Monoclinic. Three axes of unequal length, two of which intersect at right angles.
6. Triclinic. Three axes of unequal length, none of which intersect at right angles.

The macroscopic symmetry of crystals is due to the regularity of the arrangements of the elemental particles (atoms, ions, or molecules) in a lattice consisting of a three-dimensional repetition of some structural unit of fixed dimensions. The *unit cell* is the smallest unit of the crystal lattice which retains all the symmetry of the macroscopic crystal. In general, there are several possible arrangements of elementary particles which will have the symmetry associated with a given crystal system, such as the cubic system.

There are three possible arrangements of space lattices for the cubic system. As illustrated in Figure 3-2 they are:

1. Simple cubic lattice. One structural unit at each corner of the cube.
2. Face-centered cubic lattice. One unit at each corner of the cube and one unit in the center of each face of the cube.

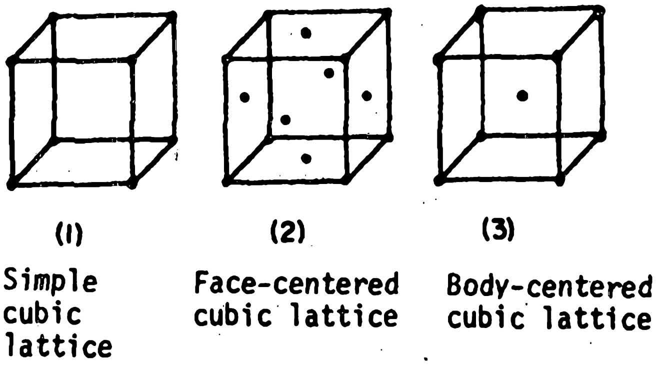

Figure 3-2. Cubic Lattices

3. Body-centered cubic lattice. One unit at each corner of the cube and one unit in the center of the cube.

X-rays may be used to determine the internal structure of crystalline materials, which can be calculated by Bragg's Law:

$$n\lambda = 2d \sin \Theta \qquad (3\text{-}16)$$

where n is the order of reflection, λ is the wavelength of the X-rays, d is the distance between two planes, and Θ is the angle of reflection.

X-ray techniques are employed to identify many solid products of combustion from pyrotechnic reactions.[4] This is especially useful when analysis of a particular product's mixture would not be practical by wet, chemical methods and where retention of the sample is desired.

Solids can be divided into three classes based upon their thermal and electrical conductivities:

1. Conductors or metals which have high conductivities which decrease with an increase in temperature.
2. Insulators which have low conductivities.
3. Semi-conductors which have intermediate conductivities which increase with rising temperature, usually as $e^{-A/T}$ where A is a constant and T is the absolute temperature.

The thermal and electrical conductivity of pyrotechnic ingredients may be contributing factors affecting the performance of a particular item. The thermal conductivity, which is of greater significance, influences the conductive heat transfer characteristics. These properties become very important in devices dependent on a functional transfer of heat such as a "pyro-switch." Such devices may be normally closed or normally open

and will either be conducting or nonconducting following the pyrotechnic reaction.

The properties of solids are markedly affected by defects[5] in crystal structure. Small amounts of impurities in an insulating material may make the material a semi-conductor. Such doped materials may also exhibit enhanced chemical activities. Departure of a crystalline compound from chemical stoichiometry, due to incorporation of extra atoms into the crystal at interstitial sites or to vacancies caused by the absence of atoms from normal sites, also results in semi-conductivity.

Point defects, including those in which an ion moves from its lattice site to an interstitial position (Frenkel defect), or those in which a pair of ions of opposite charge are missing from their lattice site (Schottky defect), do not alter the exact stoichiometry of the solid but do provide a means by which atoms can move in the solid phase. Linear defects, dislocations, provide another means for atoms to move with respect to each other in the solid phase. These defects provide mechanisms for many of the processes which occur in the solid state. They provide sites at which chemical reactions and physical changes can take place readily. The point of emergence of a dislocation at the surface is a site of increased chemical reactivity.

The presence of crystal defects in pyrotechnic ingredients can have a marked influence on the course of the reaction and, therefore, influence the characteristic behavior (including stability and output) of pyrotechnic compositions.

3-2 THERMODYNAMICS

Thermodynamics is the study of the quantitative relationships between heat and other forms of energy. In all cases, energy can be expressed as the product of two factors, an intensity factor (i.e., temperature difference), and a capacity factor (i.e., heat capacity). In the reaction of a pyrotechnic composition, the chemical energy is converted into other forms of energy, primarily heat and work. The products of combustion are heated to the reaction temperature, and, if unconfined, work can be done against the atmosphere.

In the following paragraphs, certain basic laws of thermodynamics, thermochemistry, chemical equilibrium, the concept of free energy, etc., are discussed showing their application in the field of pyrotechnics. Selected calculations, including those for adiabatic flame temperatures, which are important to the overall analysis of chemical reactions, are also presented.

3-2.1 THERMODYNAMIC RELATIONSHIPS

Thermodynamics is based on three laws and the implications derived from these laws. The application of certain thermodynamic relationships derived from the three laws is a useful tool for use in predicting the performance and outcome of many physico-chemical systems.

3-2.1.1 First Law of Thermodynamics

The first law of thermodynamics is a statement of the law of conservation of energy, i.e., that energy can be neither created nor destroyed.

The first law of thermodynamics can be expressed mathematically:

$$\Delta E = q - w \tag{3-17}$$

where q is the energy in the form of heat, transferred into or out of the system; w is the energy, in the form of work transferred to or from the system; and ΔE is the change in internal energy. If the system absorbs heat, q has a positive value; if the system does work, w has a positive value. The value of ΔE depends only on the initial and final state of the system. The quantities q and w depend on the path taken from the initial to the final state. For a cyclic process, i.e., a process which has the same initial and final stage, $\Delta E = 0$ so that $q = w$.

3-2.1.1.1 Heat Effects at Constant Volume and Constant Pressure

The heat released by a pyrotechnic reaction can raise the temperature of the reaction products, cause phase changes, and cause other chemical reactions (such as dissociation) to take place. If a chemical reaction or physical change takes place at constant volume, and only pressure-volume work is considered, the amount of work done is zero and the heat effect accompanying the reaction is equal to the change in internal energy.

$$q_v = \Delta E \tag{3-18}$$

Chemical reactions, including many pyrotechnic reactions, and physical changes may also take place at constant pressure where only pressure-volume work is considered and the heat effect is equal to the internal energy change plus the work done in expansion.

$$q_p = \Delta E + p\Delta v \qquad (3\text{-}19)$$

In this case, it is convenient to use another thermodynamic property, the enthalpy H, defined by:

$$H = E + pV \qquad (3\text{-}20)$$

Then, for a chemical reaction or phase change occurring at constant pressure, when only pressure-volume work is considered:

$$\Delta H = \Delta E + p\Delta v \qquad (3\text{-}21)$$

and the heat effect at constant pressure is equal to the change in enthalpy:

$$q_p = \Delta H \qquad (3\text{-}22)$$

If gaseous products are assumed to behave ideally:

$$\Delta H = \Delta E + \Delta nRT \qquad (3\text{-}23)$$

where $\Delta n = \Sigma n$ (products) $- \Sigma n$ (reactants) for the gaseous materials involved in the reaction. Therefore, pyrotechnic reactions involving solid reactants and the formation of gaseous products where heat is evolved (exothermic) will have a higher heat of reaction at constant volume, $\Delta E(q_v)$, than at constant pressure, $\Delta H(q_p)$. In the latter case, q_p is reduced by the heat equivalent of the increased gaseous products, ΔnRT. These relationships can be used to obtain values equivalent to the standard heat of reaction from bomb calorimetric measurements made at constant volume.

Pyrotechnic reactions take place under conditions of either constant volume, constant pressure, or combinations of both. Constant volume conditions occur for delay systems that are obturated, and constant pressure systems occur for flares, signals, smokes, and the like. In photoflash items, such as cartridges or bombs, the confined composition functions under constant volume conditions when initiated and it then continues to react at constant pressure when dispersed as the case ruptures.

3-2.1.1.2 Heat Capacity

The heat capacity of a system is defined as the quantity of heat required to raise the temperature 1°C or, expressed mathematically:

$$C = \frac{dq}{dT} \qquad (3\text{-}24)$$

Under conditions of constant volume, $dq = dE$, Equation 3-18, and the heat capacity at constant volume is equal to the change in internal energy with temperature, or:

$$C_v = \left(\frac{\partial E}{\partial T}\right)_v \qquad (3\text{-}25)$$

While the internal energy E is a function of the three variables T, P, and v; only two are required to define the system. A derivative, therefore, with respect to only one variable T is expressed as a partial derivative $\left(\frac{\partial E}{\partial T}\right)_v$ with the subscript v denoting the variable to be held constant.

At constant pressure, the heat capacity includes both the heat absorbed to increase the internal energy plus the heat equivalent of the work term $p\,dv$. Since, under these conditions, $dq = dH$, Equation 3-22, the heat capacity at constant pressure is equal to the change in enthalpy with temperature, or:

$$C_p = \left(\frac{\partial H}{\partial T}\right)_p \qquad (3\text{-}26)$$

The heat capacity at constant pressure can be calculated by equation of the form (either one):

$$C_p = a + bT + cT^2$$
$$C_p = a + bT + cT^{-2} \qquad (3\text{-}27)$$

where a, b, and c are constants. This type equation applies over a more or less limited range of temperatures and for many thermochemical calculations it is more convenient to use an average heat capacity defined by:

$$C_{p_{avg}} = \frac{\int_{T_1}^{T_2} C_p dT}{T_2 - T_1} \qquad (3\text{-}28)$$

When necessary, C_v can be obtained by subtracting R (the universal gas constant) from the value for C_p.

Heat capacity values are essential for many thermochemical calculations involving pyrotechnics. The temperature attained by the products of a pyrotechnic reaction will depend, in part, on the heat capacity of these products. Calculations of the heat balance for a given system utilize the heat capacity to obtain the enthalpy change in going from one temperature and/or state to another. The latest tables, however, provide enthalpy changes directly, making it unnecessary to calculate heat capacities independently.

3-2.1.1.2.1 Heat Capacity of Gases

According to the kinetic theory of gases, the heat capacity of ideal gases, and of monotomic real gases such as helium and argon, to relatively high temperatures is:

$$C_v = 3/2\ R = 3 \text{ cal/gmole }°K \tag{3-29}$$

$$C_p = C_v + R = 5 \text{ cal/gmole }°K \tag{3-30}$$

Diatomic real gases, including gases such as oxygen and nitrogen, and linear polytomic molecules have two degrees of rotational freedom in addition to the three degrees of freedom associated with translational motion. At normal temperatures the heat capacities of these gases are approximately:

$$C_v \cong 5/2\ R = 5 \text{ cal/gmole }°K \tag{3-31}$$

$$C_p \cong C_v + R = 7 \text{ cal/gmole }°K \tag{3-32}$$

3-2.1.1.2.2 Heat Capacity of Liquids and Solids

According to the law of Dulong and Petit, the molar heat capacities of solid elements (especially the metals) C_v and C_p are approximately 6 calories per gram-atom per degree-Kelvin. This is in agreement with the values of $3R$, i.e., 5.96 calories per gram-atom per degree-Kelvin, suggested by kinetic theory.

The molar heat capacities of solid compounds can be estimated by using Kopp's Rule which states that the heat capacity of a solid compound is approximately equal to the sum of the heat capacities of the constituent elements. In using this rule, the following atomic heat capacities are assigned to the elements: C, 1.8; H, 2.3; B, 2.7; Si, 3.8; O, 4.0; F, 5.0; P, 5.4; S, 5.4; and all others, 6.2.

Other methods are available for estimating heat capacities of solids at higher temperatures.[6] Where these values are not available, the room temperature value may be used in conjunction with a value of 7.25 calories per gram-atom per degree-Kelvin for the next transition point, assuming a linear increase of C_p with temperature.

The heat capacities of molten inorganic substances do not differ greatly from those of solid materials. When handbook values are unavailable, Kopp's Rule may also be applied to compounds by assigning the following values of atomic heat capacities to the atoms of the liquid: C, 2.8; H, 4.3; B, 4.7; Si, 5.8; O, 6.0; F, 7.0; P, 7.4; S, 7.4, and to most other elements a value of 8.0.

Other methods for estimating heat capacities of liquids and solids are available.[6] In most cases, calculations are unnecessary, as the values have been experimentally determined and may be obtained from handbook tabulations.

The heat capacity of liquids and solids decreases considerably with a decrease in temperature and is zero at absolute zero. For temperatures below 50°K, the Debye Equation applies and:

$$C_v = 464.5 \frac{T^3 \text{ calorie}}{\Theta^3 \text{ degree-Kelvin gram-atom}} \tag{3-33}$$

where T is the absolute temperature in degrees-Kelvin, and Θ is termed the characteristic temperature and is defined by:

$$\Theta = \frac{h\nu_m}{k} \tag{3-34}$$

where h is the Planck constant, k is the Boltzmann constant and ν_m is the maximum vibration frequency. These values may be found in a suitable handbook.

3-2.1.2 Second Law of Thermodynamics

The second law of thermodynamics may be expressed in many ways. A very general statement is that any spontaneous change will render a system and its surroundings closer to an ultimate state of equilibrium from which no further change can spontaneously occur. That is, any isolated system left unattended will change toward a condition of maximum probability. In order to obtain a quantitative measure of the probability or randomness

of a system, the concept of entropy has been established.

The absolute entropy S of a substance in a particular state—under specified conditions of temperature, volume and pressure and in a known state of aggregation; solid, liquid, or gas—is proportional to the logarithm of the probability of finding the substance in that state.

$$S = k \ln W \tag{3-35}$$

where k is Boltzmann's constant, and W is the probability.

Entropy, like internal energy, depends only on the initial and final states of a system and, for an infinitesimal reversible process, is defined by the equation:

$$dS = \frac{dq(\text{rev})}{T} \tag{3-36}$$

where $dq(\text{rev})$ is the heat absorbed from the surroundings in a reversible process, i.e., a process carried out in such a manner that it could be reversed by an infinitesimal change in external conditions. Entropy has the same units as heat capacity, i.e., calories per gram-atom per degree-Kelvin.

By using entropy, the second law can be expressed mathematically:

$$\Delta S \text{ system} + \Delta S \text{ surroundings} \geq 0 \tag{3-37}$$

Every spontaneous change in a system, therefore, is in a direction such that its entropy, plus that of its surroundings, increases. However, if the system alone is considered, spontaneity of chemical reactions may be treated by taking two driving forces into account; a tendency to adopt the lowest energy and a tendency to adopt the highest entropy. If the two changes are opposed, the system will proceed in the direction of the larger change. If the two quantities are exactly equal, no change will occur and the system is said to be at equilibrium. The net driving force is termed the Work Function or Helmholtz free energy A, and at constant temperature:[15,16]

$$\Delta A = \Delta E - T\Delta S \tag{3-38}$$

For a spontaneous process at constant volume and constant temperature, ΔA is always negative:

$$(\Delta A)_{T,V} < 0 \tag{3-39}$$

For pyrotechnic reactions, many of which proceed at constant pressure and temperature, the Gibbs free energy F is a more useful function. The driving force or change in free energy is important and is expressed by:

$$\Delta F = \Delta H - T\Delta S \tag{3-40}$$

In this case, the criterion of spontaneity is:

$$(\Delta F)_{T,P} < 0 \tag{3-41}$$

As a consequence of Equations 3-38 and 3-40, additional statements may be made regarding the spontaneity of chemical reactions. These are summarized in Table 3-1.

At ordinary temperatures, entropy effects are small so they have little effect on the direction of a chemical reaction unless the difference in energy ΔE or ΔH between reactants and products is relatively small. At higher temperatures, such as those resulting from pyrotechnic reactions, the relative importance of the change in entropy increases until it becomes a dominant factor. Hence, all chemical reactions which involve an increase in entropy will occur spontaneously if the temperature is high enough. A discussion of free energy and the equilibrium constant is presented in Paragraph 3-2.3.

3-2.1.3 Third Law of Thermodynamics

According to the third law of thermodynamics, the entropy of a perfect crystalline substance at 0°K is zero. Although it is impossible theoretically to attain absolute zero, the validity of the third law has been checked by experimentation. It can also be shown that the entropies of all pure chemical compounds in their stable states at 0°K are zero because their formation from the elements is: $\Delta S_o = 0$. This law states that absolute entropies or so-called third law entropies can be determined from heat capacity data extrapolated to 0°K which can be used in equilibrium calculations:

$$S = \Sigma \left(\int_{T_o}^{T} C_p \frac{dT}{T} \right) + \Sigma \frac{\Delta H_{pc}}{T} \tag{3-42}$$

where $\int_{T_o}^{T} C_p \frac{dT}{T}$, the increase in entropy, is ob-

TABLE 3-1
CRITERIA OF SPONTANEITY

Conditions	*Type of Reaction*	*Criteria*
General	Reversible	ΔS (total) $= 0$
	Spontaneous	ΔS (total) > 0
E, v constant	Reversible	ΔS (isolated system) $= 0$
	Spontaneous	ΔS (isolated system) > 0
T, v constant	Reversible	$\Delta A = 0$
	Spontaneous	$\Delta A < 0$
T, p constant	Reversible	$\Delta F = 0$
	Spontaneous	$\Delta F < 0$
S, v constant	Reversible	$\Delta E = 0$
	Spontaneous	$\Delta E < 0$
S, p constant	Reversible	$\Delta H = 0$
	Spontaneous	$\Delta H < 0$

tained for each phase by graphical integration and $\frac{\Delta H_{pc}}{T}$, the entropy increase due to a phase change, is determined for each of the phase changes. The Debye Equation (Paragraph 3-2.1.1.2.2) is used for the temperature range 0°K to approximately 50°K as experimental data are difficult to obtain in this temperature range. Absolute entropies can also be calculated by the method of statistical mechanics.[5]

3-2.2 THERMOCHEMISTRY

Thermochemistry is the study of the heat effects accompanying chemical reactions, the formation of solutions, and changes in state such as fusion and vaporization. Since the amount of heat liberated from a pyrotechnic reaction strongly influences the characteristic output, an understanding of the principles and application of thermochemistry is of vital importance.

The heat evolved (or absorbed) in a chemical reaction depends upon:

1. The properties of the products and reactants, and the amount of these substances involved.
2. The physical state of the substances involved.
3. The temperature and pressure at which the reaction takes place.
4. Whether or not the reaction is at constant volume or constant pressure.

The specific influence of these conditions is described in the paragraphs which follow.

3-2.2.1 Heats of Reaction

The heat effect associated with a pyrotechnic or other chemical reaction is the ***heat of reaction***. The ***heat of formation*** is the heat of the reaction associated with the formation of a compound from its elements. The ***heat of combustion*** is the heat of the reaction associated with the complete combustion of a substance in oxygen. The ***heat of explosion*** is the heat of reaction associated with the rapid explosive decomposition of a material in an inert atmosphere.

For pyrotechnic reactions at constant pressure, if only pressure-volume work is considered, the heat effect q_p can be obtained from the enthalpy change for the reaction as follows:

$$q_p = \Delta H \text{ (reaction)} = \Sigma H \text{ (products)} - \Sigma H \text{ (reactants)} \qquad (3\text{-}40)$$

If the reaction is a standard state reaction, where the reactants in their standard states react to give the products in their standard states and the standard heats of formation $\Delta H_T{}^\circ\ (f)$ of the elements is assumed to be zero at any given tem-

1182/1710

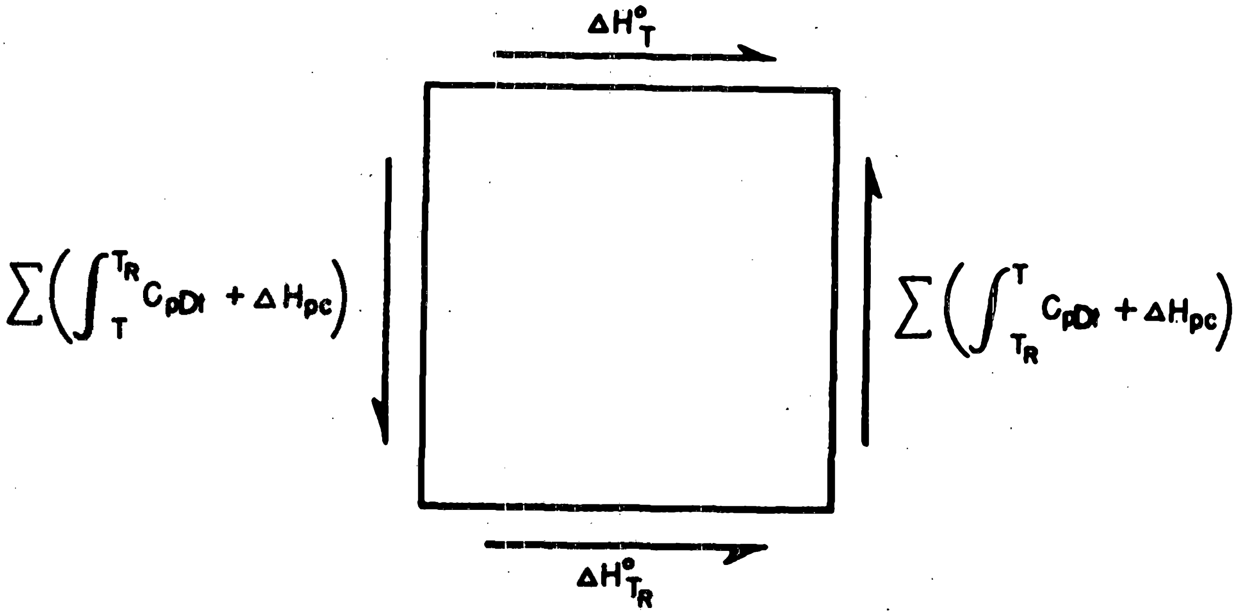

Figure 3-3. Effect of Temperature on Enthalpy Change for Chemical Reaction

perature, then the standard heat of reaction $\Delta H_T°$ (reaction) is:

$$\Delta H_T° \text{ (reaction)} = \Delta H(f)_T° \text{ (products)} - \Delta H(f)_T° \text{ (reactants)} \quad (3\text{-}41)$$

The actual choice of standard states is somewhat arbitrary. Normally, the standard state is the most stable state at one atmosphere pressure and at the given temperature. (Most tabular data are given at 0°K or 298°K.)

Most thermochemical calculations are based on tabulated standard heats of formation. The heat effect at constant pressure (q_p) can be calculated by:

$$(q_p)_T \text{ (reaction)} = \Delta H_T \text{ (reaction)} \cong \Delta H_T° \text{ (reaction)} \quad (3\text{-}45)$$

Unless the actual pressure is high, no appreciable error is introduced.

Similarly, the heat effect at constant volume (q_v) can be obtained by:

$$(q_v)_T \text{ (reaction)} = \Delta E \text{ (reaction)} \cong \Delta E_T° \text{ (reaction)} = \Sigma\Delta E(f)_T° \text{ (products)} - \Sigma\Delta E(f)_T° \text{ (reactants)} \quad (3\text{-}46)$$

3-2.2.2 Effect of Temperature on the Heat of Reaction

As illustrated schematically in Figure 3-3, the heat of reaction at any temperature T and constant pressure is:

$$\Delta H_T° = \Delta H_T°{}_R + \Sigma\left(\int_T^{T_R} C_p dT + \Delta H_{pc}\right) \text{(reactants)} + \Sigma\left(\int_{T_R}^{T} C_p dT + \Delta H_{pc}\right) \text{(products)} \quad (3\text{-}47)$$

where $\Delta H_T°$ is the heat of reaction at temperature T, $\Delta H°_{TR}$ is the heat of reaction at a reference temperature T_R, $\Sigma\left(\int_T^{T_R} C_p dT + \Delta H_{pc}\right)$ (reactants) is the heat evolved or absorbed in cooling or heating the reactants from T to T_R, including that evolved or absorbed as a result of phase changes ΔH_{pc}. Similarly, $\left(\int_{T_R}^{T} C_p dT + \Delta H_{pc}\right)$ (products) is the

heat absorbed or evolved in heating or cooling the products from T_R to T. According to Equation 3-47, if the heat evolved by cooling the reactants from the higher to the lower temperature is greater than the amount absorbed in heating the products from the lower to the higher temperature, the heat of reaction at the higher temperature will be greater than that at the lower temperature.

In cases where reactions begin and end at the same temperature and where no changes in phase are involved, the standard heat of reaction at temperature T is defined by:

$$\Delta H_T{}^\circ = \Delta H_T{}^\circ{}_R + \int_{T_R}^{T} \Delta C_p dT \qquad (3\text{-}48)$$

where $\Delta C_p = \Sigma C_p$ (products) $- \Sigma C_p$ (reactants), and $H_T{}^\circ{}_R$ is the standard heat of reaction at the reference temperature T_R. This is known as Kirchhoff's Equation and, for small temperature ranges, heat capacities may be treated as constant and the equation reduces to:

$$\Delta H_T{}^\circ = \Delta H_T{}^\circ{}_R + \Delta C_p(T\text{-}T_R) \qquad (3\text{-}49)$$

For other cases, experimental heat capacity data expressed in the form shown in Paragraph 3-2.1.1.2 must be used; however, if enthalpy tables are available, heat capacity data need not be considered as such.

Where data are required at temperatures above those listed, it may be necessary to extrapolate the data to the desired temperature.

3-2.2.3 Enthalpy Tables

Calculations of heat of reaction at different temperatures are simplified if tabular enthalpy data are available. Tables 3-2 for solid magnesium oxide, 3-3 for solid aluminum oxide, 3-4 and 3-5 for solid and liquid sodium oxide, and 3-6 for gaseous oxygen, contain these data. In these tables, standard heats of formation $\Delta H_f{}^\circ$, at different temperatures, are tabulated. In other tables only values for the enthalpy function, $H^\circ - H_{T_R}{}^\circ$, along with the heat of formation at some reference temperature, usually 0°K or 298.93°K are tabulated. The heat of reaction at any temperature becomes:

$$\Delta H_T{}^\circ = \Delta H_{T_R}{}^\circ + \Sigma(H^\circ - H_{T_R}{}^\circ) \text{ (products)} - \Sigma(H^\circ - H_{T_R}{}^\circ) \text{ (reactants)} \qquad (3\text{-}50)$$

These tables can also be used for calculations of free energy changes for chemical reactions. This is shown in Paragraph 3-2.3.5

3-2.2.4 Bond Energies[7]

Bond energy (B.E.) is defined as the average amount of energy per mole required to break a particular type of bond in a molecule. Bond energies may be calculated when heat of combustion data are available. However, of greater utility is the estimation of the heat of reaction from bond energy data for compounds for which no enthalpy data are available. In this case:

$$\Delta H = \text{B.E. (bonds broken)} - \text{B.E. (bonds formed)} \qquad (3\text{-}51)$$

Bond strengths or bond dissociation energies may differ from mean bond energies derived solely from thermochemical data on molecules and atoms.

3-2.3 FREE ENERGY AND EQUILIBRIUM

A state of chemical equilibrium exists in any chemically reacting system when no further change in composition with time can be detected provided the temperature and pressure are not altered. The criterion of equilibrium is that the change in free energy of any possible reaction under these conditions shall be zero.

$$(\Delta F)_{T,P} = 0 \qquad (3\text{-}52)$$

In order to estimate maximum flame temperatures from pyrotechnic reactions, a knowledge of the equilibrium concentrations of the combustion products is required in addition to information on the heat released. If a state of equilibrium exists among the product species, the equilibrium composition for the combustion products is fixed at a given temperature and pressure (or volume) when the atomic composition is specified.

Pyrotechnic reactions often involve the oxidation of a metal to form a refractory oxide. This reaction limits the maximum temperature attainable to the vaporization temperature of the metal oxide whether this oxide decomposes on vaporization, or not. The metals commonly used as fuels in pyrotechnics decompose on vaporization. In most cases, the metal decomposes to yield metal atoms; however, a few metal oxides, such as alum-

TABLE 3-2
THERMODYNAMIC PROPERTIES OF SOLID MAGNESIUM OXIDE
Magnesium Oxide (MgO) (Solid) Mol. Wt. = 28.32

	cal. mole^{-1} deg.$^{-1}$			kcal. mole^{-1}			
T, °K.	C°_p	S°	$-(F^\circ-H^\circ_{298})/T$	$H^\circ-H^\circ_{298}$	ΔH°_f	ΔF°_f	Log K_p
0	.000	.000	INFINITE	- 1.235	-142.702	-142.702	INFINITE
100	1.865	.608	12.488	- 1.188	-143.156	-140.918	307.961
200	6.380	3.369	7.184	- .763	-143.559	-138.501	151.340
298	8.906	6.439	6.439	.000	-143.700	-135.981	99.672
300	8.939	6.494	6.439	.017	-143.701	-135.933	99.022
400	10.148	9.252	6.807	.978	-143.705	-133.340	72.850
500	10.854	11.598	7.537	2.031	-143.654	-130.755	57.150
600	11.323	13.621	8.386	3.141	-143.583	-128.181	46.688
700	11.656	15.393	9.263	4.291	-143.513	-125.619	39.218
800	11.905	16.966	10.130	5.469	-143.457	-123.067	33.619
900	12.098	18.380	10.969	6.670	-143.425	-120.521	29.265
1000	12.251	19.663	11.775	7.888	-145.541	-117.799	25.744
1100	12.375	20.837	12.546	9.119	-145.529	-115.025	22.852
1200	12.478	21.918	13.283	10.362	-145.538	-112.252	20.443
1300	12.565	22.920	13.986	11.614	-145.567	-109.478	18.404
1400	12.638	23.854	14.658	12.874	-176.047	-106.235	16.583
1500	12.701	24.728	15.301	14.141	-175.712	-101.261	14.753
1600	12.756	25.550	15.916	15.414	-175.375	- 96.309	13.155
1700	12.804	26.325	16.505	16.692	-175.034	- 91.378	11.747
1800	12.845	27.058	17.071	17.975	-174.693	- 86.467	10.498
1900	12.882	27.753	17.616	19.261	-174.351	- 81.574	9.383
2000	12.915	28.415	18.139	20.551	-174.008	- 76.699	8.381
2100	12.945	29.046	18.644	21.844	-173.665	- 71.844	7.477
2200	12.971	29.648	19.130	23.140	-173.321	- 67.004	6.656
2300	12.994	30.225	19.600	24.438	-172.979	- 62.178	5.908
2400	13.016	30.779	20.054	25.739	-172.636	- 57.368	5.224
2500	13.035	31.311	20.494	27.041	-172.295	- 52.572	4.596
2600	13.052	31.822	20.920	28.346	-171.955	- 47.790	4.017
2700	13.068	32.315	21.333	29.652	-171.616	- 43.018	3.482
2800	13.082	32.791	21.734	30.959	-171.280	- 38.264	2.986
2900	13.095	33.250	22.123	32.268	-170.945	- 33.518	0.526
3000	13.107	33.694	22.501	33.578	-170.613	- 28.785	2.097

(JANAF Thermodynamic Tables, Interim Table Issued December 31, 1960)

inum oxide, decompose to yield a mixture of other oxide molecules. Typical of the decomposition reaction is the following general reaction:[8]

$$M_xO_y\ (1) \rightleftharpoons xM(g) + y/2\, O_2(g) \qquad (3\text{-}53)$$

where M represents a metal element. Since the reactions are reversible, the degree of decomposition will depend on the oxygen partial pressure as well as the temperature. At the high temperatures produced by pyrotechnic reactions, many other equilibria, such as the dissociations of gaseous products, relatively unimportant at lower temperatures, must be considered.

3-2.3.1 Chemical Equilibrium

According to the law of mass action as stated by C. M. Guldberg and P. Waage,[9] the rate of a chemical reaction is directly proportional to the "active masses" of the reacting materials. For any chemical reaction:

$$aA + bB + \ldots \rightleftharpoons gG + Hh \ldots$$

where the capital letter indicates a chemical species and the small letter indicates the number of moles of each species.

An equilibrium constant for this reaction, designated K, can be written in terms of concentrations:

$$K = \frac{k(f)}{k(r)} = \frac{[G]^g\,[H]^h}{[A]^a\,[B]^b} \qquad (3\text{-}54)$$

where the open brackets [ ] indicate a concentration term, $k(f)$ is the specific rate constant for the forward reaction, $k(r)$ is the specific rate constant

TABLE 3-3
THERMODYNAMIC PROPERTIES OF SOLID ALUMINUM OXIDE
Aluminum Oxide (alpha Al_2O_3) (Crystal) Mol. Wt. = 101.960

	cal. mole^{-1} deg.$^{-1}$			kcal. mole^{-1}			
T, °K.	C°_p	S°	$-(F^\circ-H^\circ_{298})/T$	$H^\circ-H^\circ_{298}$	ΔH°_f	ΔF°_f	Log K_p
0	.000	.000	INFINITE	- 2.394	-397.494	-397.494	INFINITE
100	3.069	1.024	24.184	- 2.316	-398.697	-392.241	857.201
200	12.223	5.946	13.711	- 1.553	-399.838	-385.329	421.047
298	18.889	12.174	12.174	.000	-400.400	-378.078	277.125
300	18.979	12.291	12.174	.035	-400.406	-377.940	275.316
400	22.986	18.339	12.972	2.147	-400.555	-370.418	202.378
500	25.345	23.752	14.598	4.577	-400.475	-362.891	158.612
600	26.889	28.517	16.529	7.193	-400.304	-355.389	129.444
700	27.969	32.749	18.549	9.940	-400.098	-347.920	108.620
800	28.758	36.537	20.565	12.778	-399.889	-340.481	93.011
900	29.354	39.961	22.533	15.685	-399.697	-333.066	80.875
1000	29.814	43.078	24.434	18.644	-404.522	-325.301	71.091
1100	30.176	45.938	26.261	21.644	-404.181	-317.396	63.058
1200	30.464	48.574	28.012	24.674	-403.823	-309.522	56.369
1300	30.995	51.032	29.689	27.745	-403.437	-301.680	50.715
1400	31.290	53.339	31.297	30.859	-403.019	-293.868	45.873
1500	31.620	55.509	32.839	34.004	-402.581	-286.086	41.681
1600	31.920	57.559	34.321	37.181	-402.119	-278.334	38.017
1700	32.220	59.503	35.745	40.388	-401.635	-270.612	34.788
1800	32.490	61.353	37.117	43.624	-401.133	-262.920	31.921
1900	32.760	63.116	38.439	46.886	-400.613	-255.254	29.359
2000	33.000	64.803	39.716	50.175	-400.075	-247.619	27.057
2100	33.220	66.419	40.949	53.486	-399.521	-240.011	24.977
2200	33.450	67.969	42.142	56.819	-398.956	-232.427	23.088
2300	33.670	69.461	43.298	60.175	-398.374	-224.872	21.367
2400	33.880	70.898	44.418	63.553	-397.779	-217.339	19.790
2500	34.100	72.286	45.505	66.952	-397.172	-209.834	18.343
2600	34.310	73.627	46.561	70.372	-396.550	-202.354	17.009
2700	34.520	74.926	47.588	73.814	-395.915	-194.898	15.775
2800	34.735	76.186	48.587	77.277	-536.375	-184.157	14.373
2900	34.940	77.408	49.560	80.760	-535.307	-171.598	12.931
3000	35.140	78.596	50.508	84.264	-534.227	-159.072	11.588
3100	35.340	79.751	51.433	87.788	-533.132	-146.584	10.334
3200	35.530	80.876	52.335	91.332	-532.028	-134.135	9.161
3300	35.720	81.973	53.217	94.894	-530.908	-121.718	8.061
3400	35.906	83.042	54.078	98.476	-529.777	-109.338	7.028
3500	36.095	84.085	54.921	102.076	-528.634	- 96.992	6.056

(JANAF Thermodynamic Tables, Interim Table Issued March 31, 1964)

for the reverse reaction, and K is the equilibrium constant. The concentration can be expressed as a partial pressure or as a mole fraction in addition to the more common concentration units. For actual systems, activities or fugacities should be used instead of concentrations.[5,9]

When more than one phase is present, as is true for most pyrotechnic reactions, the equilibrium is heterogeneous. Since the partial pressures of the gas phases in equilibrium with the solid phases are constant at a given temperature, they can be assumed to be incorporated into the equilibrium constant. The expression in terms of partial pressures for the equilibrium constant, therefore, will include only terms for the gaseous materials.

The equilibrium between phases is an important type of heterogeneous equilibrium. The free energies of the vapor and liquid phases are the same which leads to the derivation of the important Clausius-Clapeyron Equation:[9]

$$\frac{dp}{dT} = \frac{p\Delta H}{RT^2} \qquad (3\text{-}55)$$

In this equation, p is the vapor pressure in milli-

TABLE 3-4
THERMODYNAMIC PROPERTIES OF SOLID SODIUM OXIDE
Sodium Oxide (Na_2O) (Crystal) Mol. Wt. = 61.982

T, °K.	cal. mole⁻¹ deg.⁻¹ C_p°	S°	$-(F^\circ - H^\circ_{298})/T$	kcal. mole⁻¹ $H^\circ - H^\circ_{298}$	ΔH°_f	ΔF°_f	Log K_p
0							
100							
200							
298	17.436	17.990	17.990	.000	- 99.400	-90.125	66.060
300	17.454	18.098	17.990	.032	- 99.398	-90.067	65.610
400	18.442	23.254	18.687	1.827	-100.647	-86.862	47.457
500	19.430	27.475	20.034	3.720	-100.601	-83.417	36.460
600	20.418	31.105	21.584	5.713	-100.428	-79.995	29.137
700	21.406	34.327	23.178	7.804	-100.138	-76.612	23.918
800	22.394	37.249	24.757	9.994	- 99.737	-73.277	20.017
900	23.382	39.944	26.297	12.283	- 99.235	-69.998	16.997
1000	24.370	42.459	27.788	14.670	- 98.641	-66.780	14.594
1100	25.358	44.828	29.231	17.157	- 97.966	-63.629	12.641
1200	26.346	47.077	30.625	19.742	-143.685	-59.625	10.859
1300	27.334	49.224	31.974	22.426	-142.423	-52.670	8.854
1400	28.322	51.286	33.280	25.209	-141.067	-45.817	7.152
1500	29.310	53.274	34.547	28.090	-139.615	-39.064	5.691
1600	30.298	55.197	35.778	31.071	-138.067	-32.409	4.427
1700	31.286	57.064	36.975	34.150	-136.420	-25.854	3.324
1800	32.274	58.880	38.142	37.328	-134.681	-19.401	2.355
1900	33.262	60.651	39.280	40.605	-132.846	-13.044	1.500
2000	34.250	62.382	40.392	43.980	-130.916	-6.791	.742

(JANAF Thermodynamic Tables, Interim Table Issued June 30, 1962)

meters of mercury, T is the absolute temperature, R is the universal gas constant, and ΔH is the heat of vaporization in calories per gram-mole. If ΔH can be considered constant over the temperature range of interest, then:

$$\log p = \left(\frac{-\Delta H}{2.3R}\right)\left(\frac{1}{T}\right) + \text{Constant} \qquad (3\text{-}56)$$

This equation is of the same form as the empirical equation given in paragraph 3-1.2.1 relating change in vapor pressure and temperature. An equation of similar form relates the sublimation pressure and temperature.

The heterogeneous metal oxide decomposition equilibrium illustrated by Equation 3-53 is important to the study of pyrotechnic reactions. The expansion for the equilibrium constant for this reaction in terms of partial pressures K_p can be written:

$$K_p = (p_{O_2})^{y/2} (p_M)^x \qquad (3\text{-}57)$$

where p_{O_2} is the partial pressure of the oxygen and p_M is the partial pressure of the metal vapor.

3-2.3.2 The LeChatelier Principle

The LeChatelier principle states that if a stress is brought to bear on a system in equilibrium the system will adjust itself to diminish the applied stress. For example, in the decomposition of a metal oxide in a confined system, the partial pressures will increase and the reaction shifts to the left. A higher temperature is required to decompose the oxide.

When heat is absorbed by a chemical reaction, an increase in temperature favors the reaction; on the other hand, if heat is evolved by the reaction, an increase in temperature will favor the reverse reaction.

3-2.3.3 Free Energy and the Equilibrium Constant

For any chemical reaction the change in free energy is given by

$$\Delta F = RT \ln \frac{Q}{K} \qquad (3\text{-}58)$$

where K is the equilibrium constant. Q is a continuous function similar in form to K (Equation

TABLE 3-5
THERMODYNAMIC PROPERTIES OF LIQUID SODIUM OXIDE
Sodium Oxide (Na_2O) (Liquid) Mol. Wt. = 61.982

T, °K.	C°_p (cal. mole^{-1} deg.$^{-1}$)	S° (cal. mole^{-1} deg.$^{-1}$)	$-(F^\circ-H^\circ_{298})/T$ (cal. mole^{-1} deg.$^{-1}$)	$H^\circ-H^\circ_{298}$ (kcal. mole^{-1})	ΔH°_f (kcal. mole^{-1})	ΔF°_f (kcal. mole^{-1})	Log K_p
0							
100							
200							
298	27.000	17.889	17.889	.000	- 93.996	-84.691	62.077
300	27.000	18.056	17.890	.050	- 93.977	-84.632	61.652
400	27.000	25.823	18.949	2.750	- 94.320	-81.562	44.561
500	27.000	31.848	20.948	5.450	- 93.468	-78.470	34.298
600	27.000	36.771	23.188	8.150	- 92.587	-75.553	27.519
700	27.000	40.933	25.433	10.850	- 91.688	-72.787	22.724
800	27.000	44.538	27.601	13.550	- 90.777	-70.148	19.163
900	27.000	47.719	29.663	16.250	- 89.864	-67.624	16.421
1000	27.000	50.563	31.613	18.950	- 88.958	-65.201	14.249
1100	27.000	53.137	33.455	21.650	- 88.069	-62.872	12.491
1200	27.000	55.486	35.194	24.350	-133.673	-59.704	10.873
1300	27.000	57.647	36.839	27.050	-132.396	-53.592	9.009
1400	27.000	59.648	38.398	29.750	-131.122	-47.579	7.427
1500	27.000	61.511	39.878	32.450	-129.851	-41.655	6.069
1600	27.000	63.253	41.285	35.150	-128.584	-35.816	4.892
1700	27.000	64.890	42.626	37.850	-127.317	-30.056	3.864
1800	27.000	66.433	43.906	40.550	-126.055	-24.371	2.959
1900	27.000	67.803	45.130	43.250	-124.797	-18.755	2.157
2000	27.000	69.278	46.303	45.950	-123.543	-13.209	1.443
2100	27.000	70.596	47.429	48.650	-122.289	- 7.725	.804
2200	27.000	71.852	48.511	51.350	-121.041	- 2.297	.228
2300	27.000	73.052	49.552	54.050	-119.795	3.070	- .292
2400	27.000	74.201	50.555	56.750	-118.554	8.390	- .764
2500	27.000	75.303	51.523	59.450	-117.316	13.649	- 1.193
2600	27.000	76.362	52.458	62.150	-116.084	18.866	- 1.586
2700	27.000	77.381	53.362	64.850	-114.857	24.031	- 1.945
2800	27.000	78.363	54.238	67.550	-113.637	29.151	- 2.275
2900	27.000	79.310	55.086	70.250	-112.421	34.234	- 2.580
3000	27.000	80.226	55.909	72.950	-111.213	39.269	- 2.861

(JANAF Thermodynamic Tables, Interim Table Issued June 30, 1962)

3-54) but which applies to the "concentrations" or partial pressures of the products and reactants at any time during a particular reaction. For real gases and other substances, the K and Q should be terms of activities or fugacities. If the reaction is a standard state reaction, the hypothetical reaction in which the reactants in their standard states at one atmosphere react to give products in their standard states at one atmosphere, Q becomes unity and

$$\Delta F^\circ = -RT \ln K \tag{3-59}$$

For a gaseous reaction involving gases which can be considered ideal:

$$\Delta F^\circ = -RT \ln K_p \tag{3-60}$$

where K_p is the equilibrium constant in terms of partial pressures. For example, the equilibrium constant for the decomposition of a metal oxide, Equation 3-57 is related to the standard free energy change for the reaction, Equation 3-59, as follows:

$$\Delta F^\circ = -RT \ln K_p = -RT \ln (p_{O_{2(g)}})^{y/2}(p_{M(g)})^x \tag{3-61}$$

where p_{O_2} is the partial pressure of the oxygen and p_M is the partial pressure of the metal vapor. Hence, the stability of the oxide can be calculated from frequency data.

3-2.3.4 Free Energy Calculations

Standard free energy changes for chemical reac-

TABLE 3-6
THERMODYNAMIC PROPERTIES OF OXYGEN
Oxygen, Diatomic (O_2) (Reference State—Ideal Gas) Mol. Wt. = 32.00

T, °K.	C_p° (cal. mole^{-1} deg.$^{-1}$)	S° (cal. mole^{-1} deg.$^{-1}$)	$-(F^\circ - H^\circ_{298})/T$ (cal. mole^{-1} deg.$^{-1}$)	$H^\circ - H^\circ_{298}$ (kcal. mole^{-1})	ΔH°_f (kcal. mole^{-1})	ΔF°_f (kcal. mole^{-1})	Log K_p
0	.000	.000	INFINITE	- 2.075	.000	.000	.000
100	6.741	41.522	55.142	- 1.362	.000	.000	.000
200	6.871	46.233	49.641	- .682	.000	.000	.000
298	7.020	49.004	49.004	.000	.000	.000	.000
300	7.023	49.047	49.004	.013	.000	.000	.000
400	7.196	51.091	49.282	.724	.000	.000	.000
500	7.431	52.722	49.812	1.455	.000	.000	.000
600	7.670	54.098	50.414	2.210	.000	.000	.000
700	7.883	55.297	51.028	2.988	.000	.000	.000
800	8.063	56.361	51.629	3.786	.000	.000	.000
900	8.212	57.320	52.209	4.600	.000	.000	.000
1000	8.336	58.192	52.765	5.427	.000	.000	.000
1100	8.439	58.991	53.295	6.266	.000	.000	.000
1200	8.527	59.729	53.801	7.114	.000	.000	.000
1300	8.604	60.415	54.283	7.971	.000	.000	.000
1400	8.674	61.055	54.744	8.835	.000	.000	.000
1500	8.738	61.656	55.185	9.706	.000	.000	.000
1600	8.800	62.222	55.608	10.583	.000	.000	.000
1700	8.858	62.757	56.013	11.465	.000	.000	.000
1800	8.916	63.205	56.401	12.354	.000	.000	.000
1900	8.973	63.749	56.776	13.249	.000	.000	.000
2000	9.029	64.210	57.136	14.149	.000	.000	.000
2100	9.084	64.652	57.483	15.054	.000	.000	.000
2200	9.139	65.076	57.819	15.966	.000	.000	.000
2300	9.194	65.483	58.143	16.882	.000	.000	.000
2400	9.248	65.876	58.457	17.804	.000	.000	.000
2500	9.301	66.254	58.762	18.732	.000	.000	.000
2600	9.354	66.620	59.057	19.664	.900	.000	.000
2700	9.405	66.974	59.344	20.602	.000	.000	.000
2800	9.455	67.317	59.622	21.545	.000	.000	.000
2900	9.503	67.650	59.893	22.493	.000	.000	.000
3000	9.551	67.973	60.157	23.446	.000	.000	.000
3100	9.596	68.287	60.415	24.403	.000	.000	.000
3200	9.640	68.592	60.665	25.365	.000	.000	.000
3300	9.682	68.889	60.910	26.331	.000	.000	.000
3400	9.723	69.179	61.149	27.302	.000	.000	.000
3500	9.762	69.461	61.383	28.276	.000	.000	.000
3600	9.799	69.737	61.611	29.254	.000	.000	.000
3700	9.835	70.006	61.834	30.236	.000	.000	.000
3800	9.869	70.269	62.053	31.221	.000	.000	.000
3900	9.901	70.525	62.267	32.209	.000	.000	.000
4000	9.932	70.776	62.476	33.201	.000	.000	.000
4100	9.961	71.022	62.682	34.196	.000	.000	.000
4200	9.988	71.262	62.883	35.193	.000	.000	.000
4300	10.015	71.498	63.081	36.193	.000	.000	.000
4400	10.039	71.728	63.275	37.196	.000	.000	.000
4500	10.062	71.954	63.465	38.201	.000	.000	.000
4600	10.084	72.176	63.652	39.208	.000	.000	.000
4700	10.104	72.393	63.836	40.218	.000	.000	.000
4800	10.123	72.606	64.016	41.229	.000	.000	.000
4900	10.140	72.814	64.194	42.242	.000	.000	.000
5000	10.156	73.019	64.368	43.257	.000	.000	.000
5100	10.172	73.221	64.540	44.274	.000	.000	.000
5200	10.187	73.418	64.708	45.292	.000	.000	.000
5300	10.200	73.613	64.875	46.311	.000	.000	.000
5400	10.213	73.803	65.038	47.332	.000	.000	.000
5500	10.225	73.991	65.199	48.353	.000	.000	.000
5600	10.237	74.175	65.358	49.377	.000	.000	.000
5700	10.247	74.356	65.514	50.401	.000	.000	.000
5800	10.258	74.535	65.668	51.426	.000	.000	.000
5900	10.267	74.710	65.820	52.452	.000	.000	.000
6000	10.276	74.883	65.970	53.479	.000	.000	.000

(JANAF Thermodynamic Tables, Interim Table Issued March 31, 1961)

tions $\Delta F_T°$ can be calculated from the standard free energies of formation, $\Delta F_T°(f)$:

$$\Delta F_T° = \Sigma \Delta F_T°(f) \text{ products} = \Sigma \Delta F_T°(f) \text{ reactants} \tag{3-62}$$

Standard free energy of formation of the elements in their standard state at one atmosphere pressure and at the given temperature is taken as zero.

The standard free energy change and the associated equilibrium constant (Equation 3-58) are functions of temperature. The change in free energy, the enthalpy change ΔH, and the temperature are related by the Gibbs Helmholz equation which, for a standard state reaction, is:

$$\frac{\Delta H° - \Delta F°}{T} = \frac{-d\Delta F°}{dT} = \frac{d(RT \ln K)}{dT} \tag{3-63}$$

If $\Delta H°$ can be considered constant over the range of temperature, or is an average value:

$$\frac{\Delta F°}{RT} = -\log K_p = + \frac{\Delta H°}{2.3RT} + \text{Constant} \tag{3-64}$$

If $\Delta H°$ cannot be treated as a constant over the temperature range, the calculation of the change in the equilibrium constant with temperature is more complicated.

3-2.3.5 Tabulated Free Energy Values

Calculations involving free energy changes at any temperature are made easier if tabulated values are available for the standard free energy of formation at various temperatures. Tables 3-2, 3-3, 3-4, 3-5, and 3-6 contain this information in addition to the information on standard enthalpies of formation. In these particular tables, the standard free energies of formation of the compound from the elements in their standard states, along with the equilibrium constant for the formation reaction, are tabulated for various temperatures. In other tabulations the free energy function

$\dfrac{F_T° - F_{T_R}}{T}$ is tabulated for various temperatures

along with the standard free energies of formation at some reference temperature, where T is the reaction temperature and T_R is the reference temperature.

Then:

$$\Delta F_T° = \Sigma \Delta F_{T_R}°(f) \text{ products} - \Sigma \Delta F_{T_R}°(f) \text{ reactants} + \Sigma T \left(\frac{F_T° - F_{T_R}}{T}\right) \text{ products} - \Sigma T \left(\frac{F_T° - F_{T_R}}{T}\right) \text{ reactants} \tag{3-65}$$

The reference temperatures normally used are 298°K or 0°K. The free energy change at these two temperatures is related by:

$$\Delta F_{298}° = \Sigma \Delta H_0°(f) \text{ products} - \Sigma \Delta H_0°(f) \text{ reactants} + \Sigma 298 \left(\frac{F_{298}° - H_0°}{298}\right) \text{ products} - \Sigma 298 \left(\frac{F_{298}° - H_0°}{298}\right) \text{ reactants} \tag{3-66}$$

3-2.4 ADIABATIC FLAME TEMPERATURE

The heat produced by an exothermic reaction raises the temperature of the products formed to the reaction temperature. This maximum temperature can be calculated from a knowledge of the equilibrium composition of the combustion products and of the energy released by the reaction. The calculations assume adiabatic conditions, i.e., no heat is lost to or gained from the surroundings, and all the heat released is utilized in raising the temperature of the products and unreacted reactants to the flame temperature. At constant pressure, where the heat effect associated with a given reaction is equal to its enthalpy change:

$$\Delta H_T° = \Delta H_{T_R}° \text{ (reaction)} + \Sigma \Delta H \text{ (diss)} + \Sigma \Delta H_{pc} + \Sigma \int_{T_R}^{T_T} C_p \text{ (products) } dT \tag{3-67}$$

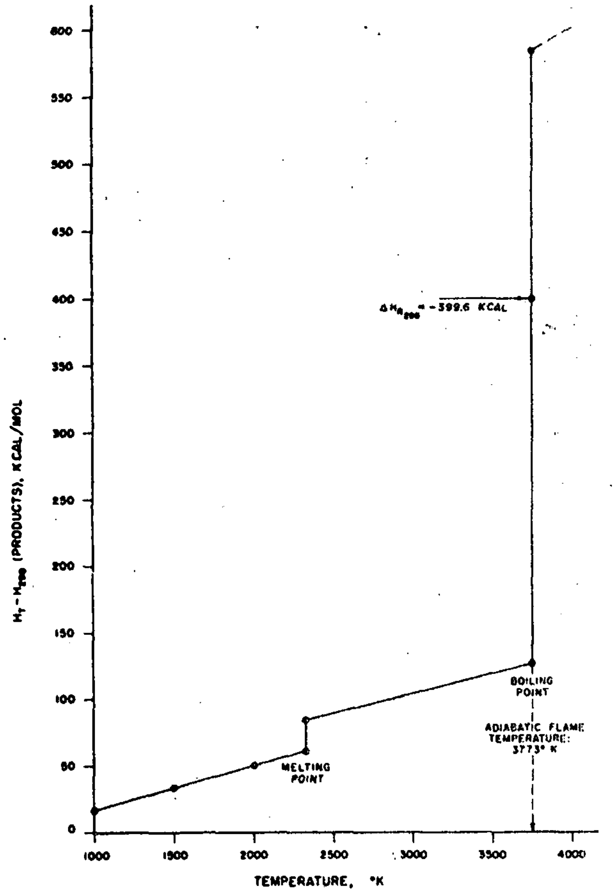

Figure 3-4. Enthalpy of Aluminum Oxide Versus Temperature

where $\Delta H_{T_R}{}^\circ$ is the enthalpy change for the reaction at a reference temperature T_R; $\Sigma \Delta H$ (diss) is the summation of the enthalpy changes associated with the dissociation of gaseous products and with ionization if the flame temperatures are sufficiently high; $\Sigma \Delta H_{pc}$ is the summation of the enthalpy changes associated with phase changes in the reaction products; and $\Sigma \int_{T_R}^{T_T} C_p$ (products) dT is the amount of heat necessary to raise the reaction products to the flame temperature.

Before calculating the enthalpy change for the reaction, equations must be obtained for the molar composition of the combustion products allowing for all elements and equilibrium relationships.[10] The calculation of the adiabatic flame temperature is an iterative process for which use of a high speed computer is recommended.

For simpler cases, where the number of product species is small, the flame temperature can be calculated by a trial and error process until a temperature is found at which all the energy released by the chemical reaction will be absorbed.

The calculation of the adiabatic temperature for some chemical reactions, including those involving the oxidation of metals, can be simplified by preparing an enthalpy or heat-content graph. This graph consists of a plot of the heat content (above the selected reference temperature for the reaction products) as a function of temperature, using tabulated values for $H_T{}^\circ - H_{T_R}{}^\circ$; $H_T{}^\circ - H^\circ{}_0$ or heat capacity; heat of fusion; heat of vaporization; and heat of dissociation. The heat of reaction is located on the ordinate of the plot and the horizontal line is drawn from this value until it intersects the heat content curve.[11] The adiabatic flame temperature is read from the abscissa.

3-2.5 SAMPLE THERMODYNAMIC CALCULATIONS

The following sample calculations have been selected to illustrate the application of thermodynamics to pyrotechnic reactions.

Example 1. The adiabatic flame temperature for aluminum burning in a stoichiometric amount of oxygen can be calculated as follows. The overall stoichiometric reaction is:

$$2Al\ (s) + 1.5O_2\ (g) \rightarrow Al_2O_3\ (s)$$

The heat of reaction at 298°K is the same as the heat of formation of Al_2O_3 (s) $\sim$ 400 kilocalories per mole. (See paragraph 3-2.2.) The heat content plot for this reaction is given in Figure 3-4 where the reference temperature is taken as 298°K.

Approximately 400 kilocalories are released in the formation of solid aluminum oxide at the reference temperature of 298°K. As shown in Figure 3-4, approximately 140 kilocalories of this energy are required to raise one mole of aluminum oxide to its boiling point. The difference (400 to 140 kilocalories) is consumed in vaporization of the

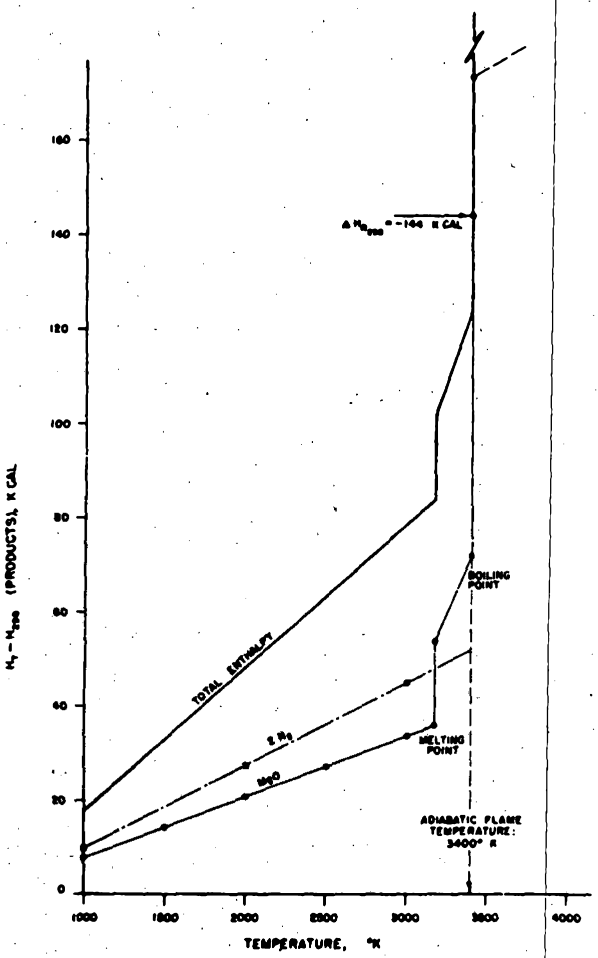

Figure 3-5. Enthalpy of Products of Magnesium-Air Reaction

liquid aluminum oxide. The vaporization of Al_2O_3 (1) at approximately 3800°K may take place as follows:

$$Al_2O_3(1) \rightarrow 2AlO(g) + O(g)^*$$

For this reaction, the standard enthalpy change is:

$$H°_{298°K} = 456 \text{ kilocalories per mole}$$

As there is not enough energy available to vaporize all the aluminum oxide, the maximum temperature is limited to the boiling point of aluminum oxide, or approximately 3800°K.

Example 2. The adiabatic flame temperature for magnesium burning in air (20% oxygen, 80% nitrogen) can be calculated in a similar manner. The reaction, in this case is:

$$Mg(s) + .5O_2(g) + 2N_2(g) \rightarrow MgO(s) + 2N_2(g)$$

The heat of reaction at the reference temperature of 298°K is the heat of formation of MgO(s), or 144 kilocalories per mole. Figure 3-5 is a heat content plot for the products of this reaction where it is assumed that magnesium oxide vaporizes by dissociation into atoms. It must be noted that the nitrogen in the air must be heated to the flame temperature. The adiabatic flame temperature is limited to the boiling point of magnesium oxide, about 3400°K. If the magnesium were burned in pure oxygen, the calculated adiabatic flame temperature would still be limited to about 3400°K.

Example 3. Compositions containing magnesium and sodium nitrate are used in many illuminating flares. There are several possible ways for this reaction to proceed which, in turn, determine relative amounts of magnesium and sodium nitrate required for the stoichiometric (balanced) chemical reaction. Two of the possible stoichiometric reactions are:

1. $5Mg(s) + 2NaNO_3(s) \rightarrow 5MgO(s) + Na_2O(s) + N_2(g)$

and:

2. $6Mg(s) + 2NaNO_3(s) \rightarrow 6MgO(s) + 2Na(s) + N_2(g)$

For the first reaction, the ratio of the weight of sodium nitrate required to weight of magnesium is:

$$\frac{2(85)}{5(24.3)} = 1.40$$

and for the second reaction is:

$$\frac{2(85)}{6(24.3)} = 1.166$$

The heat of reaction for the first reaction at 298°K is:

$$\Delta H°_{298} = [5(-143.8) + -99.4] - [5(0) + 2(-115.0)] = \underline{-588.4 \text{ kilocalories}}$$

and for the second reaction is:

$$\Delta H°_{298} = [6(-143.8) + 2(0)] - [6(0) + 2(-115.0)] = \underline{-632.8 \text{ kilocalories}}$$

From the heat content plots for the two reactions, Figures 3-6 and 3-7, the adiabatic flame temperature is nearly the same for both reactions: approximately 3280°K for the first reaction, and 3400°K (the boiling point of magnesium oxide) for the second reaction.

The reaction equation which best represents the reaction to produce the products which exist in the hot (over 2500°K) portions of the flame plume can be selected from thermodynamic considerations in the following manner.

At 2500°K, the free energy change associated with the reaction:

$$Na_2O(1) \rightleftharpoons 2Na(g) + .5O_2(g)$$

is given by Equation 3-62 (Paragraph 3-2.3.4).

$$\Delta F^\circ_{2500^\circ K} = [2(0) + .5(0)] - [1(+13.649)] = \underline{-13.649 \text{ kilocalories}}$$

and by Equation 3-64 (Paragraph 3-2.3.4)

$$-13.649 = \frac{-(2)(2.3)(2500)\log K_p}{1000}$$

$$K_p = 15.4$$

$$\text{Also: } K_p = (P_{Na})^2 \cdot (P_{O_2})^{1/2} = (4P_{O_2})^2 \cdot (P_{O_2})^{1/2}$$

$$\text{and: } (P_{O_2}) = .746 \text{ atm}$$

Since the calculated (P_{O_2}) is greater than the partial pressure of oxygen in the air, 0.2 atmosphere, the compound Na_2O (1) is not thermodynamically stable at 2500°K. Therefore, these calculations indicate that the second reaction better represents the stoichiometry of the overall reaction leading to the formation of the product species present at a flame temperature of 2500°K.

However, the first reaction better represents the overall reaction to form the products which are stable at room temperature since similar calculations indicate that $Na_2O(s)$ is the more stable sodium-containing species at room temperature.

Example 4. IM-11 is a widely used incendiary mixture. It consists of 50 percent magnesium-aluminum alloy (50/50) and 50 percent barium nitrate by weight. This mixture is fuel rich and if all the fuel is to burn, extra oxygen must be obtained from the air. If it is assumed that sufficient oxygen is available to oxidize the metal fuels, a balanced reaction can be written.

On a basis of 200 grams of IM-11, the moles of each constituent are: $Ba(NO_3)_2$, 100/261.4 = 0.38; Mg, 50/24.32 = 2.06; Al, 50/26.97 = 1.86. Accordingly, the reaction is:

$$2.06Mg + 1.86Al + .38Ba(NO_3)_2 + 1.48O_2 + 5.92N_2 \rightarrow .38BaO + 6.30N_2 + 2.06MgO + .93Al_2O_3$$

The heat of reaction at 298°K is:

$$\Delta H^\circ_{298} = [.38(-133.5) + 6.3(0) + 2.06(-143.7) + .93(-400.4)] - [2.06(0) + 1.86(0) + .38(-237.06) + 1.48(0) + 5.92(0)] = 628.6 \text{ kilocalories}$$

The heat content diagram for this system is shown in Figure 3-8. As indicated on this diagram, the adiabatic flame temperature is approximately 3400°K.

Less heat is evolved if it is assumed that oxygen from the air is not available for the reaction.

Example 5. The optimum composition for a magnesium-sodium nitrate illuminating composition, to be burned at low altitudes where oxygen is available from the atmosphere, can be estimated by assuming that the amount of magnesium in excess of the stoichiometric amount which can be vaporized by the stoichiometric reaction, based on the amount of sodium nitrate, can burn in the air. For the magnesium-sodium nitrate system the stoichiometric reaction is (see Example 3):

$$6Mg(s) + 2NaNO_3(s) \rightarrow 6MgO(s) + 2Na(s) + N_2(g)$$

for which the heat of reaction ΔH°_{298} is 632.8 kilocalories. The number of moles of magnesium n which could be vaporized by this amount of energy is:

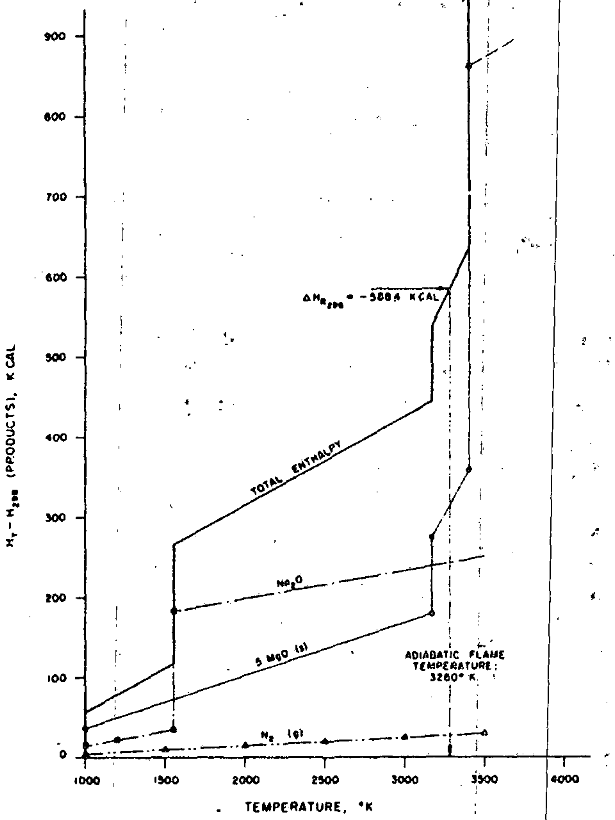

Figure 3-6. Enthalpy of Products of Magnesium-Sodium Nitrate Flare (Reaction 1)

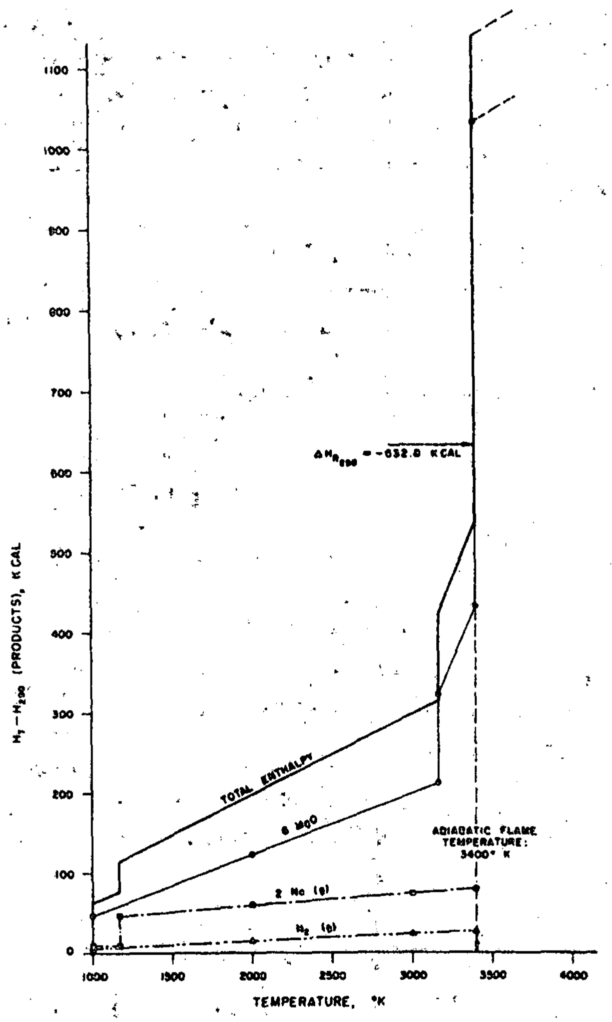

Figure 3-7. Enthalpy of Products of Magnesium-Sodium Nitrate Flare (Reaction 2)

$$n = \frac{\Delta H^\circ_{298}}{\Delta H[Mg(v)1390^\circ K - Mg(s)298^\circ K]} = \frac{632.8}{40.75} = 15.52 \text{ moles}$$

so that the weight percentage of magnesium for the optimum composition would be:

$$\frac{(6+n)\,(MW\ Mg)}{(6+n)\,(MW\ Mg) + 2(MW NaNO_3)} = \frac{(21.52)\,(24.3)}{(21.52)\,(24.3) + 2(85.01)} \times 100 = 75.5\%$$

where MW stands for the molecular weight.

3-2.6 SUMMARY OF THERMOCHEMICAL CALCULATIONS

Results of thermochemical calculations such as those illustrated in the foregoing examples, can be summarized as shown in Tables 3-7 and 3-8. All calculations on these sheets are for a reference temperature 298.15°K and one atmosphere pressure.

3-3 CHEMICAL KINETICS

Chemical kinetics is concerned with the velocity of reactions and the intermediate steps (mechanisms) by which the reactants are ultimately

TABLE 3-7
EXAMPLE OF THERMOCHEMICAL CALCULATIONS: LANTHANUM-POTASSIUM PERCHLORATE REACTION
THERMOCHEMICAL CALCULATIONS*

	%	*Mol Wt*	*ΔHf*	*Density, g/ml*
REACTANTS				
Lanthanum(s)	72.6	138.92	0.	6.15
Potassium Perchlorate(s)	27.4	138.55	103.6	2.52
PRODUCTS				
Lanthanum Oxide(s)	85.5	325.84	458	6.51
Potassium Chloride(s)	14.5	74.56	104.2	1.99

REACTION CALCULATIONS

	$8La$	$+\ 3KClO_4$	$\longrightarrow$	$4La_2O_3$	$+\ 3KCl$
Stoichiometric:	8(138.92)	+ 3(138.6)	$\longrightarrow$	4(325.84)	+ 3(74.56)
Thermal:	8(0)	+ 3(103.6)	$\longrightarrow$	4(458)	+ 3(104.2)

Wt Reactants, g	1521.2
Theoretical Density (calc.), g/ml	4.41
Heat of Reaction (calc.), Kcal	1834
cal/g	1205
cal/ml	5330
Adiabatic Temp (calc.), °K App.	4750
Gas Volume (calc.), liters	0

EQUIVALENTS

1.0 g La = 0.445 g $KClO_4$ = 1742 cal
1.0 g $KClO_4$ = 2.650 g La = 4400 cal

THEORETICAL OPTIMUM COMPOSITION

Lanthanum, %	85
Potassium Perchlorate, %	15

*All calculations refer to 298.15°K.

converted into the products. As most pyrotechnic reactions involve heterogeneous systems, the relatively simple kinetic equations developed for homogeneous systems are useful but not adequate. These equations do, however, provide background for understanding of the chemical kinetics involved in a heterogeneous reaction. It is to be noted that the rate of a pyrotechnic reaction, which is affected by external temperature, pressure confinement, composition, particle size, consolidation, and other interrelated factors, is usually best determined experimentally.

3-3.1 MOLECULARITY OF REACTIONS

The simple, intermediate reactions by which the reactants are ultimately converted into products can be classified as:

1. Unimolecular. A reaction in which only one molecule reacts to yield the product(s).
2. Bimolecular. A reaction in which two molecules (of the same or of different kinds) react to yield the product(s).
3. Termolecular. A reaction in which three molecules react to form the product(s).

TABLE 3-8
EXAMPLE OF THERMOCHEMICAL CALCULATIONS:
ZIRCONIUM-OXYGEN REACTION
THERMOCHEMICAL CALCULATIONS*

	%	Mol Wt	ΔHf	Density, g/ml
REACTANTS				
Zirconium(s)	74.3	91.22	0	6.49
Oxygen (g)	25.7	32.0	0	
PRODUCTS				
Zirconium Oxide(s)	100	123.22	261.5	5.6

REACTION CALCULATIONS

	$Zr(s) + O_2(g) \longrightarrow ZrO_2(s)$
Stoichiometric:	$91.22 + 32 \longrightarrow 123.22$
Thermal: ΔHr	$0 + 0 \longrightarrow 261.5$
Wt Reactants, gs	123.22
Theoretical Density (calc.), g/ml	—
Heat of reaction (calc.), Kcal	261.5
cal/g	2120
Adiabatic Temp (calc.), °K	App. 4500
Gas Volume, liters/g	0

EQUIVALENTS

One g Zr = 0.346 g O_2 = 2860 cal

One g O_2 = 2.89 g Zr = 8250 cal

*All calculations refer to 298.15°K.

(There are few, if any, termolecular reactions.)

The overall reactions occurring in the burning of a pyrotechnic composition consist of a sequence of many simple intermediate unimolecular, bimolecular and termolecular reactions.

3-3.2 ORDER OF REACTION

The instantaneous rate of a chemical reaction, as measured by the rate of disappearance of one of its reactants, can be written:

$$\frac{-dA}{dt} = k[A]^m [B]^n [C]^o \ldots \qquad (3\text{-}68)$$

where the minus sign indicates the disappearance of reactant A, the symbol [] indicates concentrations, k is the specific rate constant, and the exponents m, n, and o, are empirically determined. For gaseous reactions, concentrations are often expressed in terms of partial pressures. Similar expressions could be written for the disappearance of other reactants or for the appearance of any of the products.

The overall order of the reaction is the sum of the exponents of the "concentration" terms. The order of a reaction, with respect to one reactant, is the exponent of the concentration term for that reactant. Examples are:

$$\textit{Zero Order:} \ \frac{-d[A]}{dt} = k \qquad (3\text{-}69)$$

The reaction rate is a constant and is independent of the concentration of the reactants.

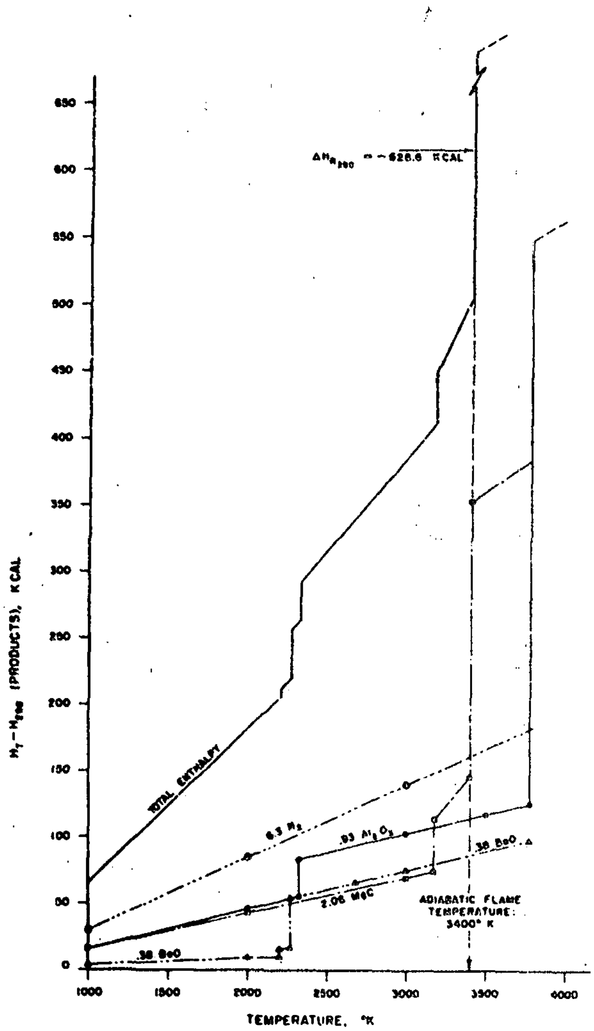

Figure 3-8. Enthalpy of IM-11 Incendiary Mixture

First Order:

$$\frac{-d[A]}{dt} = k[A] \qquad (3\text{-}70)$$

The reaction rate is proportional to the concentration of a reactant. In this case, half-life (the time required for one-half of the reactant present at any given time to disappear) is independent of the initial concentration.

Second Order:

$$\frac{-d[A]}{dt} = k[A][B] \qquad (3\text{-}71)$$

or:

$$\frac{-d[A]}{dt} = k[A]^2 \qquad (3\text{-}72)$$

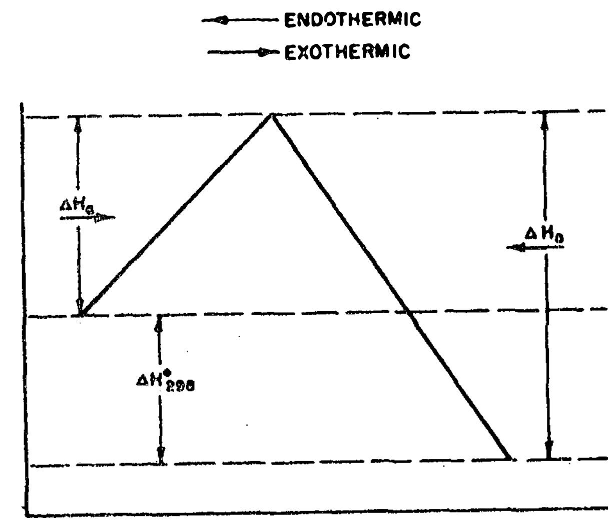

Figure 3-9. The Relationship Between Heat of Reaction and Heat of Activation

The reaction rate is proportional to the product of the concentrations of two reactants or to the concentration of one reactant squared.

Only a very few reactions follow zero, first, second, or third order reactions. Most chemical reactions, especially at the high temperatures involved in most pyrotechnic reactions experimentally determined, are complicated combinations of many simpler reactions. These complications include consecutive reactions, reverse reactions, and side reactions. Hence, it is possible for the order of a reaction to be fractional.[12]

3-3.3 INFLUENCE OF TEMPERATURE ON REACTION RATES

The reaction rate is strongly dependent on temperature. A quantitative relationship proposed by Arrhenius relating the specific rate constant and the absolute temperature is:

$$K = s \exp\left[\frac{-E_a}{RT}\right] \qquad (3\text{-}73)$$

where k is the specific rate constant, s is a constant, E_a is the activation energy, R is the gas constant, and T is the absolute temperature. Another somewhat more complicated relationship, based on the theory of absolute reactions rates, is:[13]

$$k = \left(\frac{RT}{Nh}\right)\left(\exp\left[\frac{\Delta S_a}{R}\right]\right)\left(\exp\left[\frac{-\Delta H_a}{RT}\right]\right) \quad (3\text{-}74)$$

where k is the specific rate constant, R is the gas constant, N is the Avogadro's number, h is Planck's constant, S_a is the entropy of activation, H_a is the enthalpy of activation, and T is the absolute temperature. The relationship between the heat of activation for the forward and reverse reactions and the heat of reaction:

ΔH (reaction) $= \Delta H_a$ (forward) $- \Delta H_a$ (reverse)

is illustrated in Figure 3-9 for an exothermic reaction.

3-3.4 CHAIN REACTIONS

Theoretical and experimental results indicate that atom-molecule and radical-molecule reactions normally require much smaller activation energies than reactions between two molecular species. A variety of chemical processes proceed by mechanisms which involve free radicals or atoms in a sequence of reactions forming a chain. These processes include thermal and photo-chemical decomposition processes, polymerization and depolymerization processes under the influence of heat and light, as well as a variety of oxidations and halogenations involving hydrocarbons which can give rise to the production of flames and explosions.

In a straight chain reaction, a chain carrier—which may be a free radical, free atom, or an excited molecule or atom—is produced by some suitable primary reaction. This chain carrier reacts with a molecule to produce another molecule and another chain carrier which, in turn, reacts with another molecule to produce another chain carrier. As long as the chain remains unbroken, the disappearance of one chain carrier is accompanied by the formation of another chain carrier. The chain can be broken by the removal of the chain carriers, as the result of reactions between chain carriers or between the chain carrier and other reactive materials, or by the collision of a chain carrier with the wall of the containing vessel.

In some cases, the reaction of a chain carrier with a molecule may produce more than one chain carrier. This multiplication of the number of chain carriers, or chain branching, can lead to an infinitely rapid rate for the reaction. Explosions resulting from chain branching are definitely different from thermal explosions. In a thermal explosion, because of the exothermal nature of the reaction and the difficulties attending heat removal, the temperature of the system rises rapidly and an extremely rapid reaction or explosion may result. A branched chain explosion can take place even though isothermal conditions are maintained.

3-3.5 HETEROGENEOUS REACTIONS

In heterogeneous systems, reactions take place at phase boundaries. While the kinetics of chemical reactions involving more than one phase is less developed than that for homogeneous systems, the overall process includes at least three steps:

1. Transport of reactants to the phase boundary.
2. Reaction at the phase boundary.
3. Transport of products away from the phase boundary.

As indicated earlier, a series of reactions will have relatively simple kinetics if the rate of one step is much slower than any of the others. Heterogeneous reactions, therefore, are divided into two general types: (a) transport rate controlled, and (b) phase boundary reaction rate controlled.

Reactions involving a gas as one of the reactants are frequently phase boundary reaction rate controlled at low temperatures and pressures; however, many of these reactions become transport rate controlled at higher temperatures. For condensed phase reactions, the transport rates will be even slower so that reactions are often transport rate controlled even at low temperatures.

3-3.6 IGNITION AND PROPAGATIVE BURNING

The burning of solid propellants and consolidated pyrotechnic mixtures are similar in many respects. When raised to their ignition temperature, they undergo preignition reactions followed by an ignition reaction. If conditions are favorable,

the reaction front moves at a nominally constant velocity. Propagative burning involves recurring ignition as the reaction front progresses, therefore, ignition and propagative burning processes must be considered together.

3-3.6.1 Ignition

The overall process of ignition involves heating a portion of the combustible—such as a propellant, pyrotechnic mixture, or a combustible material in air—to its ignition temperature, the minimum temperature required for the initiation of a self-sustaining reaction. While the overall ignition process can be stated simply, the mechanism of ignition is not known in detail. An ignition stimulus, which can be reduced to the effect of heat absorption, starts a sequence of preignition reactions involving crystalline transitions, phase changes, or thermal decomposition of one or more of the ingredients. In many cases involving propellants and pyrotechnic mixtures, a gaseous phase is formed and combustion starts in the gaseous phase. This is true for wood and similar materials where combustion starts in the gaseous phase after the formation of gaseous combustible intermediates by thermal decomposition of the fuel. Combustion of liquid fuels also starts and takes place in the gaseous phase.

The preignition period begins with the application of the ignition stimulus and ends with the start of self-sustaining combustion. During this period, the rate of heat transfer to, the rate of heat production in, and the rate of heat loss from that portion of the material being ignited, are important. As the temperature rises, the rate of the heat producing reactions will increase as predicted by the Arrhenius equation (Equation 3-73). The rate of heat loss will also increase with temperature but, because of the exponential form of the Arrhenius equation, a temperature may be attained at which the rate of heat generation is greater than the rate of heat loss and ignition will result.

The time to ignition can be expressed by an equation similar in form to the Arrhenius equation.[13,14]

$$t = A \exp \frac{E_a}{RT}$$

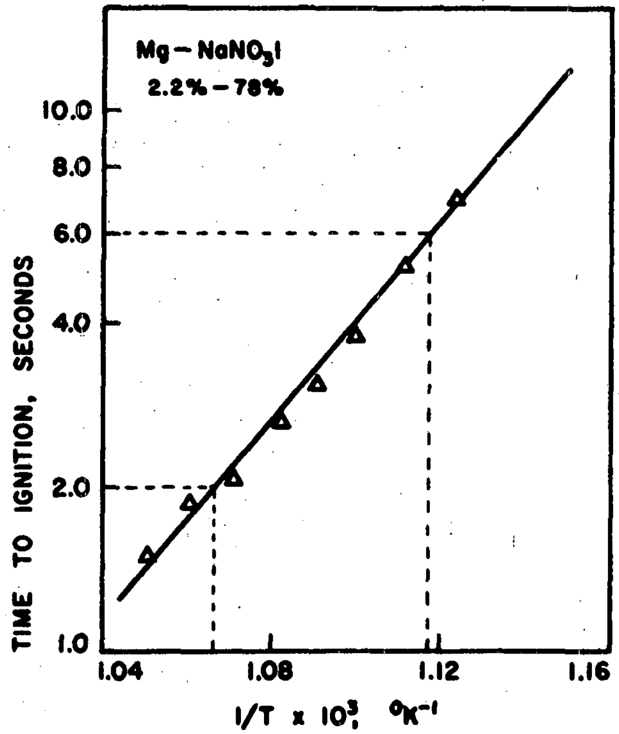

Figure 3-10. Ignition Time-Temperature Plots for a Binary Pyrotechnic Mixture

where t is the time to ignition at the temperature T in degrees absolute; E_a, the activation energy, is a constant; R is the universal gas constant; and A is a constant, depending upon the material. A large number of propagatively reacting systems, such as explosives, propellants, and pyrotechnic compositions follow this type of equation. The value obtained for activation energy for the ignition process can be considered a measure of the sensitivity of the composition to heat. It will depend, partly, on the specific experimental conditions.

Time to ignition is often measured[15,16] by quickly immersing the sample in a suitable container into a liquid such as molten lead maintained at a constant temperature and observing the time to ignition. As shown in Figure 3-10[17] the results obtained are presented in an Arrhenius type plot in which the natural logarithm of the time to ignition is plotted against the reciprocal of the absolute temperature. An average value for the activation energy for ignition can be obtained by:

$$E_a = [2.3(\text{slope})]R$$

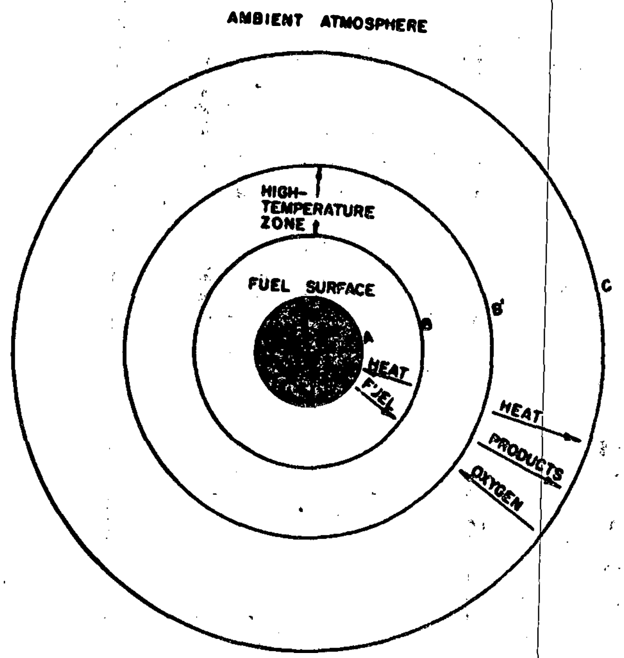

Figure 3-11: Model for Burning of Aluminum Particles

where the factor 2.3 is the conversion factor for natural logarithms into common logarithms and R is the gas constant expressed in cal per degree-mole.

By using the data plotted in Figure 3-10, the activation energy E_a for ignition of the magnesium-sodium nitrate system can be calculated in the following manner:

Slope of line:

$$M = \frac{y_2 - y_1}{x_2 - x_1} = \frac{2.3(\log 6 - \log 2)}{10^{-3}(1.118 - 1.064)}$$

$$= 2.3 \times 10^3 \left(\frac{0.7782 - 0.3010}{0.054}\right)$$

$$= 2.3 \times 10^3 \left(\frac{0.4772}{0.054}\right) = 20.35 \times 10^3$$

Activation energy:

$$E_a = (20.35 \times 10^3)2$$
$$= 40.7 \times 10^3 \text{ cal/mole}$$
$$= 40.7 \text{ Kcal/mole}$$

3-3.6.2 Burning of Metal Particles[8]

A primary characteristic of the burning of a metal is the limitation of the temperature attained by the boiling point of the resultant oxide. Although the heats of combustion of metals are relatively high, most of the heat energy obtained from this reaction is used up by the heat of vaporization and dissociation of the oxide. Two models for metal particle combustion which have been proposed based on studies of the burning of aluminum differ mainly in the treatment of the condensed oxide formed by the combustion reaction.[18]

As hollow oxide spheres are formed in the combustion of aluminum, one of the models for self-sustained combustion consists of a vaporizing droplet of aluminum which is surrounded by a bubble of molten aluminum oxide. The reaction rate is determined by diffusion through the alumina shell.[19]

The other model consists of a vaporizing droplet of aluminum surrounded by a detached reaction zone where the condensed alumina product appears as fine droplets. The reaction rate is controlled by the vapor-phase diffusion of aluminum and atmospheric oxidant to the reaction zone.[20] This model, which appears to be most in agreement with the experimental data obtained for burning aluminum particles,[18] is illustrated schematically in Figure 3-11.

Within the limitation of this model, it is possible to predict conditions favoring vapor-phase flames, surface combustion, or no combustion. For those conditions resulting in vapor-phase combustion, the burning rate of spherical droplets W can be expressed as:[21]

$$W = kr^n \tag{3-77}$$

where r is the radius of the droplet, k is a constant involving, among other factors, the latent heat of vaporization, and n is a constant normally having a value near 1.

3-3.6.3 Burning of Solid Propellants

The burning of solid propellants has been extensively studied and, in some cases, the mechanism of burning is reasonably well established. Solid propellants can be classified into two general types, homogeneous propellants and composite propellants. Homogeneous propellants are commonly called double base, or colloidal propellants, because they consist of a colloidal mixture of nitrocellulose and an explosive plasticizer, usually nitro-

glycerin. Relatively small amounts of other materials are added to improve the properties of the propellant. A composite propellant resembles a pyrotechnic mixture in that it is an intimate mixture of a fuel (reductant) and an oxidizer. It consists of a finely divided, solid oxidizing agent in a plastic, resinous, or elastomeric matrix which normally provides the fuel for the combustion reaction. Solid reducing materials are sometimes included and other minor constituents may be added to modify the properties of the binder or to change the burning characteristics.

Combustion processes in solid propellants, as in pyrotechnic mixtures, are complicated because of the several processes involved in the transformation of the solid material, at ambient temperatures, into gaseous, liquid, and solid combustion products at the flame temperature. In general, for all solid propellants, the temperature of the propellant a short distance below the burning surface is not affected by the combustion of the propellant. In propagative burning as the burning surface advances, the unburned propellant is heated, and the temperature of the material increases to the point where the propellant decomposes into volatile fragments. In some cases, liquefaction may occur prior to the chemical reactions which comprise the combustion process.

The solid phase processes for double base propellants, which take place in a 10^{-3} to 10^{-2} centimeter thick layer, are completed at relatively low temperatures, near 600°C. The gas phase reactions can be considered as taking place in three zones. The first zone exists adjacent to the burning surface, and is called the fizz zone, where some exothermic reactions may take place. In the second zone, called the preparation or dark zone, activated intermediates are formed without heat production. When a sufficient concentration of activated intermediates is developed, the final reaction occurs in the flame zone; this reaction produces the constant pressure combustion temperature. The thickness of each of the zones increases with a decrease in ambient pressure.

The burning of composite propellants, as well as pyrotechnic mixtures involving intimate mixtures of fuel and oxidizer, is more complicated than the burning of a double base propellant. In general,

T_m = MAXIMUM REACTION TEMPERATURE
T_i = MINIMUM IGNITION TEMPERATURE
T_f = FUSION TEMPERATURE
T_{tr} = TRANSITION TEMPERATURE
T_0 = AMBIENT TEMPERATURE
$\Delta z'$, $\Delta z''$, $\Delta z'''$, $\Delta z''''$ = LENGTH OF ZONES
1 = REACTION ZONE
2 = ZONE OF FUSION
3 = ZONE OF CRYSTALLINE TRANSITION
4 = HEAT CONDUCTION ZONE
z = DIRECTION
V = VELOCITY OF BURNING

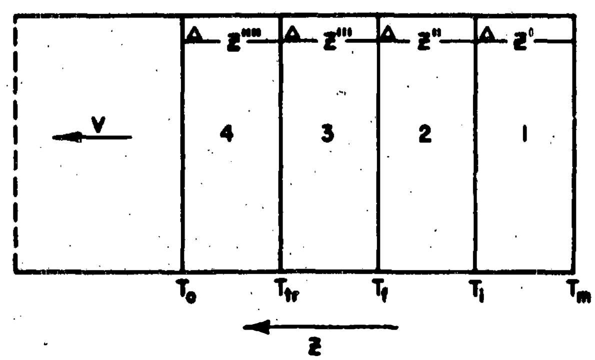

Figure 3-12. Model for Steady State Progressive Burning

as for a double base propellant, the burning of a composite propellant involves the formation of active gaseous intermediates from the fuel and oxidant, which then react.

3-3.6.4 Rate of Propagative Burning[22]

The steady state burning rate of a propagative burning system is determined, basically, by the temperature produced by the reaction and by the amount of heat transferred, mainly by conduction, to the unburned composition. These quantities, in turn, are influenced by the ratio of ingredients, external pressure and temperature, rate of chemical reaction, thermal conductivity, particle size distribution, and the porosity of the consolidated composition.

If it is assumed that heat transfer by radiation and diffusion of material can be neglected—and if heat losses from the side are insignificant—the

model for steady state propagative burning illustrated in Figure 3-12 is applicable. It is further assumed that the burning composition can be separated into reaction and preignition zones defined by the limits of the maximum reaction temperature, the minimum ignition temperature, and the ambient temperature, respectively.

Heat, produced as a result of chemical reactions in the reaction zone, is transferred to the adjacent, unreacted composition in the preignition zones, thus affecting physical transitions and initiating preignition reactions. It is assumed that the temperature gradient across the reaction and preignition zones is constant with time, and that the position of these zones changes linearly with time. Other assumptions are that the specific heat, thermal conductivity, and density of the composition remain essentially constant over the temperature ranges involved.

For this model, the following equation can be obtained for the linear rate of burning V:

$$V = \frac{\sum_i Q N_i n_i [A_i]^{x_i} \, s \, \exp\left[\frac{E_a}{RT}\right]}{\sum_i D C_m \nabla T} \qquad (3\text{-}78)$$

where Q is the heat of reaction; s is the Arrhenius frequency factor; N_i is the number of fuel particles per unit volume; n_i is the number of molecules of ith species, which has an activity A_i; and x_i is the order of the reaction. E_a is the energy of activation, R is the universal gas constant, T the absolute temperature, D the density, C_m the mean specific heat, and ∇T the temperature gradient. According to this equation, the rate of propagative burning is directly proportional to the net heat of reaction, specific rate, concentration of reactants, and specific surface, and is inversely proportional to the density of the composition, mean specific heat, and temperature gradient across the reaction and preignition zones. The rate of burning is also proportional to the thermal conductivity.

The effect of particle size on the rate of propagative burning can be estimated by assuming that the rate of the chemical reaction is proportional to the rate of change in volume of the spherical particles and that the rate of change in the radius of a reacting particle can be expressed as an exponential function of the particle mass. Under

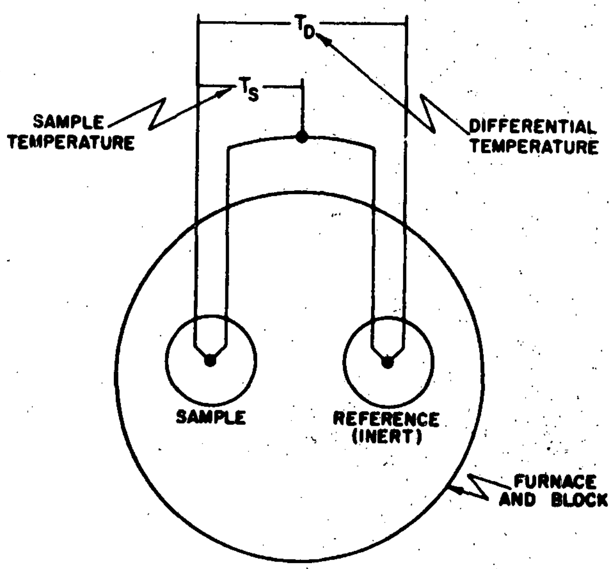

Figure 3-13. Differential Thermal Analysis Thermocouple Circuit

these conditions, A_i in Equation 3-78 is equal to the mass of a metal particle m, and x_i is equal to 0.67 (as the surface area of a particle is proportional to its volume to the 0.67th power) plus a constant h, defined by the equation.

$$dr/dt = k(m)^h$$

Other reaction parameters will remain essentially constant when the particle size of the metal fuel is changed, and:

$$V_u = V_s \frac{N_u}{N_s} \left(\frac{m_u}{m_s}\right)^{(h + 0.67)} \qquad (3\text{-}79)$$

The subscript u refers to the mixture with an unknown burning rate, and the subscript s refers to standard. The constant h in the above equation often has a value of about 0.18. More accurate results are obtained if h is determined experimentally for each mixture.

The derived equation does not include a pressure term; however, several of the parameters which influence the burning rate are affected by

changes in ambient pressure. The pressure dependence of the burning rate v, for many similar propagative burning reactions at higher pressures, is sometimes given as:

$$v = bp^n \tag{3-80}$$

or by:

$$v = a + bp^n$$

where a, b and n are constants, and p is the pressure. At the lower pressure normally encountered in burning of pyrotechnic items, the relationships between the linear burning rate and the pressure may be more complicated.

3-4 THERMOANALYTICAL TECHNIQUES[28]

The thermoanalytical techniques of differential thermal analysis (DTA) and thermogravimetry analysis (TGA) are versatile experimental tools which are finding increased application in chemical research. Differential thermal analysis involves the heating of either the ingredient or the mixture under study and a thermally inert reference material to elevated temperatures at a constant rate, while continuously measuring the temperature differences between them as a function of sampled temperature and time.

Although the techniques of DTA have been widely used in the study of clays, minerals, and soils, relatively little work has been reported utilizing this method to investigate and characterize the thermal decomposition of inorganic compounds. In Figure 3-13, a schematic diagram illustrates the basic measurements required in DTA. The temperature differential between an inert reference compound—e.g., ignited Al_2O_3—and the material under study is measured and recorded as they are both heated to elevated temperatures at a constant rate. The differential temperature is measured at T_D and the sample temperature at T_S.

The reference material chosen should be thermally inert and undergo no endothermal or exothermal reactions over the temperature range under consideration. Consequently, the inert sample heats at a rate equal to that of the furnace. When the sample being analyzed undergoes an endothermal reaction, its temperature remains relatively constant or increases very slowly. Therefore, since the temperature of the inert sample is constantly increasing, an endothermal differential temperature results. Conversely, an exothermal reaction causes the sample temperature to increase more rapidly than the reference temperature, and the result is an exothermal differential. When there is no thermal reaction, the sample and reference compounds heat

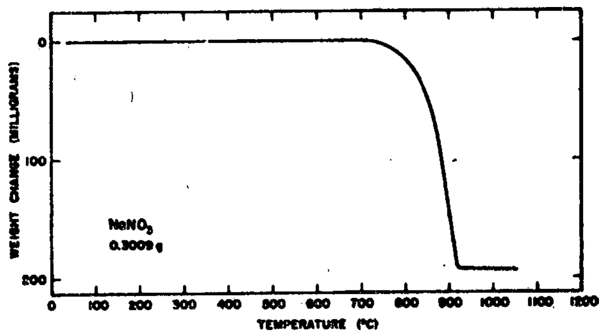

Figure 3-14.1. Thermogravimetric Curve for the Ingredient Sodium Nitrate

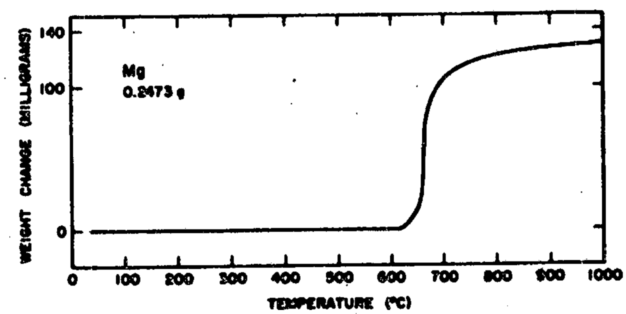

Figure 3-14.2. Thermogravimetric Curve for the Ingredient Magnesium

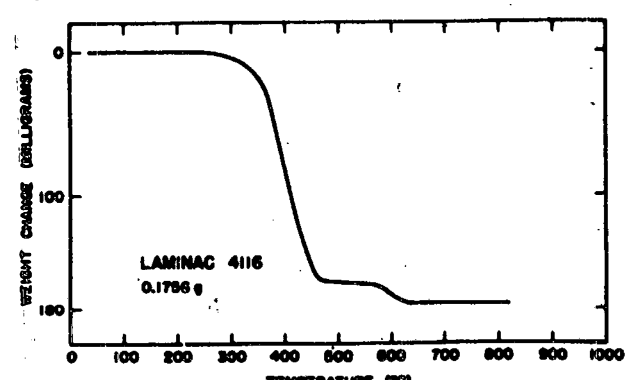

Figure 3-14.3. Thermogravimetric Curve for the Ingredient Laminac 4116

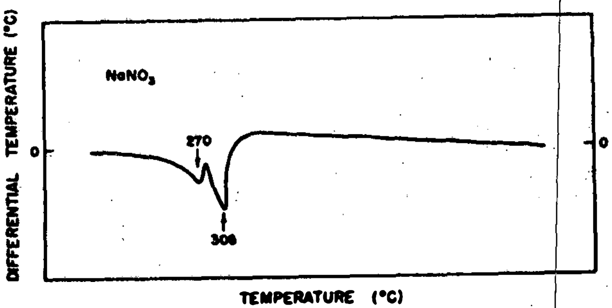

Figure 3-15.1. Differential Thermal Analysis Curve for the Ingredient Sodium Nitrate

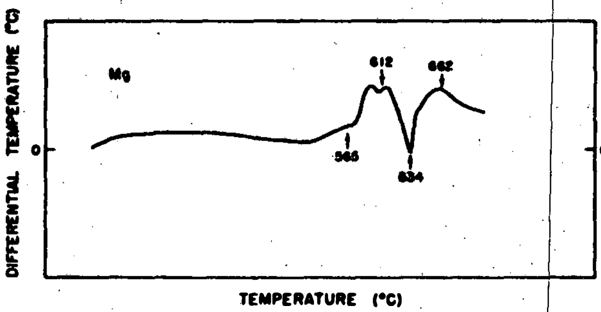

Figure 3-15.2. Differential Thermal Analysis Curve for the Ingredient Magnesium

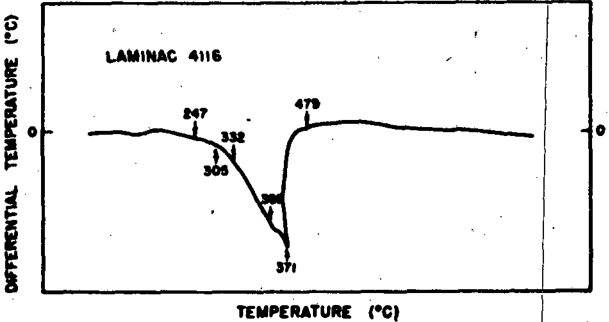

Figure 3-15.3. Differential Thermal Analysis Curve for the Ingredient Laminac 4116

at the same rate and no differential temperature is observed. Dehydration of a hydrated or hygroscopic substance is an endothermic process as are those of fusion boiling. Transitions involving transformations from one crystal lattice to another, or the free rotation of ions in a lattice are, most often, endothermal processes; however, there are several isolated exceptions to this general rule. Decomposition reactions may be either endothermal or exothermal depending upon the system and temperature under consideration. Oxidation of a material such as a metal powder by a gas, e.g., oxygen or nitrogen, involves the evolution of heat and is, therefore, an exothermal reaction. Oxidation-reduction reactions normally are exothermal processes, particularly when considering reactants such as metal fuels and solid oxidants. Since these types of phenomena are indicated by the DTA curves obtained, these curves may be used to characterize the system under study in terms of its thermal reactions, both physical and chemical. Integration of areas under endothermal bands also has been used to obtain a semi-quantitative estimate of the amount of one or more of the ingredients present.

Thermogravimetry consists of continuously weighing a sample as it is heated, either at a constant temperature or to elevated temperatures at a constant rate. Curves are obtained as a function of temperature or time. Since thermogravimetric curves are quantitative representations of weight changes, they can be related to the chemical and physical changes taking place in the sample as it is heated, and can often be used to determine the nature of the intermediate and final reaction products.

Typical results obtained by thermogravimetric and differential thermal analyses techniques are illustrated by the results obtained in a study of the pyrotechnic illuminating mixture composed of 54 percent magnesium, 36 percent sodium nitrate, and 10 percent Laminac.[24] The thermogravimetric studies under normal atmospheric conditions indicate that all three ingredients undergo thermal reactions involving weight change as a function of furnace temperature, as illustrated in Figures 3-14.1 through 3-14.3. Sodium nitrate exhibits a weight loss at temperatures from 700°C to 1000°C which corresponds to a complete conversion to sodium oxide. The curve also shows a point of inflection at about 850°C due to the concurrent decomposition of the intermediate product, sodium nitrite. Magnesium shows a continuous gain in weight which begins at about 625°C and continues on past the maximum temperature. The curve varies in slope, becoming perceptibly steeper at 650°C, and markedly less steep at 680°C. This weight gain is attributed to the successive formation of magnesium nitride and magnesium oxide.

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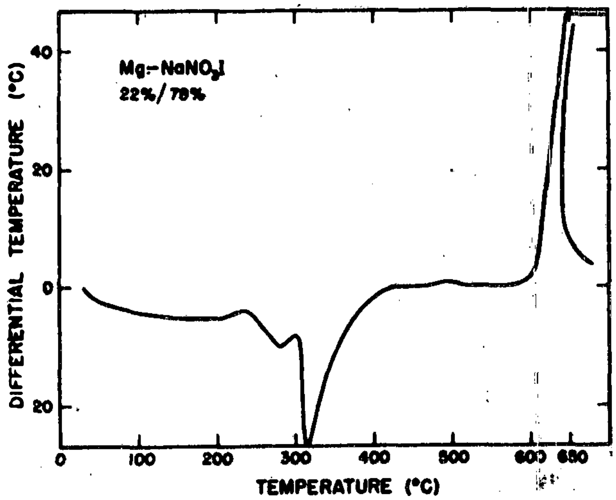

Figure 3-16.1. Differential Thermal Analysis Curve for the Magnesium-Sodium Nitrate Mixture (Curve I)

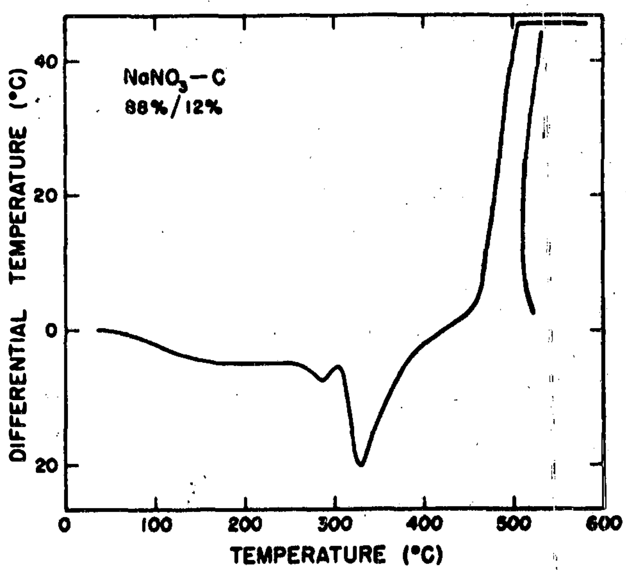

Figure 3-16.2. Differential Thermal Analysis Curve for the Sodium Nitrate-Carbon Mixture

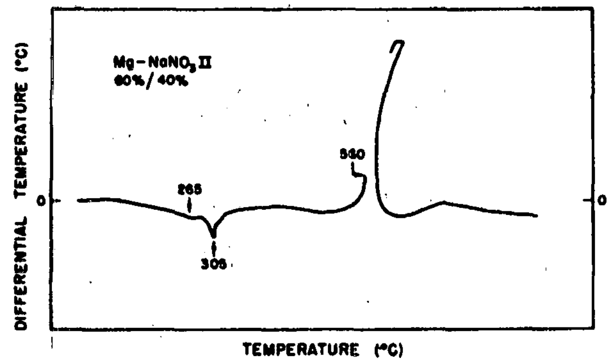

Figure 3-16.3. Differential Thermal Analysis Curve for the Magnesium-Sodium Nitrate Mixture (Curve II)

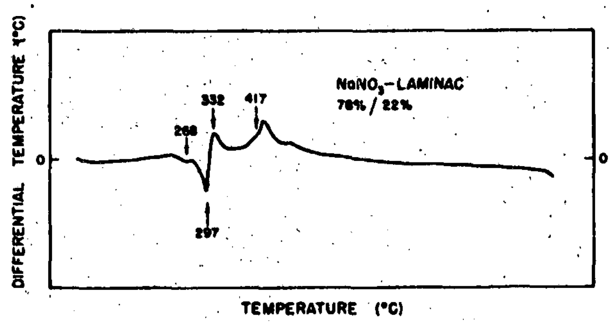

Figure 3-16.4. Differential Thermal Analysis Curve for the Sodium Nitrate-Laminac Mixture

Polymerized Laminac first shows a continuous weight loss, extending from about 100°C to 500°C, which markedly changes in slope at 350°C. This loss is followed by another loss, ending at 625°C, which represents a loss in weight equivalent to the initial weight of the sample. This loss is due to chemical degradation of the polymer to carbon, which is then completely oxidized.

The DTA curves for the ingredients are illustrated in Figures 3-15.1 through 3-15.3. The only thermal effect exhibited by sodium nitrate is endothermic crystalline transition at 270°C, immediately followed by endothermic fusion at 306°C. The differential thermogram of magnesium shows a double exothermic peak beginning at about 565°C, which may be due to the formation of magnesium nitride or magnesium oxide on the surface of the metal, or to reaction with the glass tube. The double peak culminates in the endothermic fusion of magnesium. The DTA curve of polymerized Laminac displays only one broad, endothermic band, beginning at about 250°C, with a peak temperature of 371°C. However, it appears as though several overlapping reactions are responsible for the heat absorption. At 305°C, a colorless liquid condenses on the upper part of the sample tube. At 332°C, there are dense, white fumes escaping from the tube. At 479°C, after the endotherm is over, the sample gives off dense, yellow fumes and some charring is observed in the tube.

As shown in Figures 3-16.1 through 3-16.5, the binary fuel mixture, magnesium-Laminac, gives

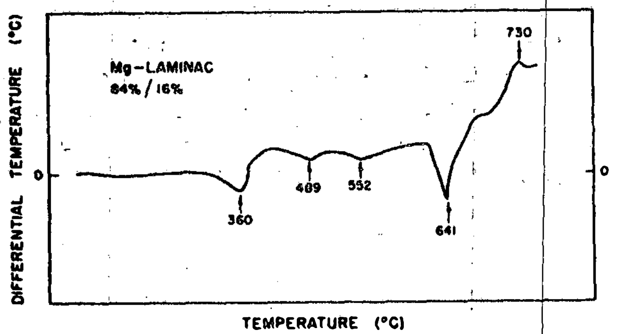

Figure 3-16.5. Differential Thermal Analysis Curve for the Magnesium-Laminac Mixture

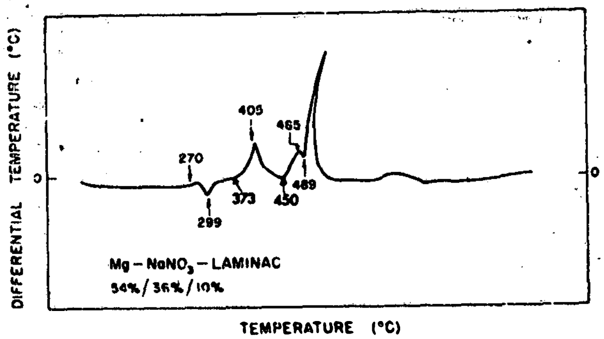

Figure 3-17.2. Differential Thermal Analysis Curve for the Magnesium-Sodium Nitrate-Laminac Composition

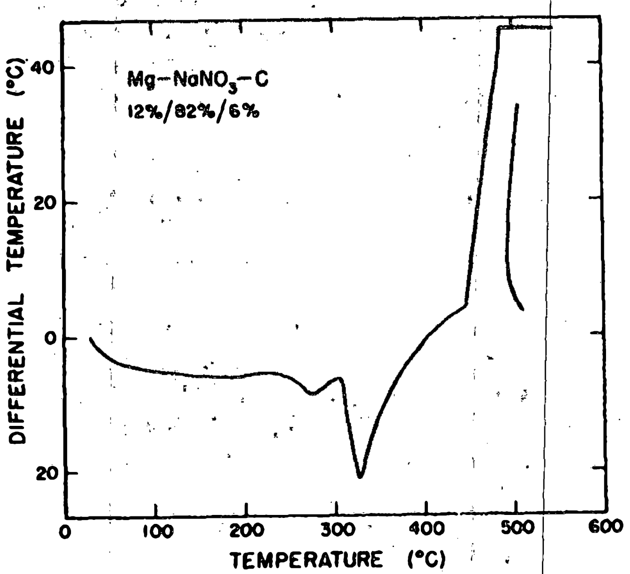

Figure 3-17.1. Differential Thermal Analysis Curve for the Magnesium-Sodium Nitrate-Carbon Composition

DTA evidence of the thermal decomposition of the Laminac present by several shallow endotherms prior to the sharply endothermic fusion of magnesium. The magnesium fusion endotherm is followed by an exothermal reaction, probably the oxidation of molten magnesium. The absence of any exothermal peak prior to magnesium fusion suggests that, although the Laminac does not react with the bulk of the metal, it protects the solid magnesium from reaction with air. The four binary fuel-oxidant mixtures did ignite. For all the ignitible sodium nitrate compositions run on the time-base apparatus, the endotherms corresponding to the crystalline transition of sodium nitrate are very small because only very small samples were used. The fuel-rich system 60-40 magnesium-sodium nitrate, Curve II, used in the test, ignited at 560°C. The DTA curve shows the endothermic crystalline transition of sodium nitrate at 265°C, and its fusion at 305°C, in addition to the sharply exothermic ignition. The stoichiometric mixture, Curve I, for the reaction:

$$Mg + NaNO_3 \rightarrow MgO + NaNO_2$$

containing only 22 percent magnesium, ignited at 613°C and displayed endotherms at 270° and 310°C which were caused, respectively, by the crystalline transition and fusion of sodium nitrate. Sodium nitrate-Laminac ignited with an apparently small evolution of heat at 417°C that may have been due to a combination of small sample size and formation of gaseous products. The differential thermogram exhibits the crystalline transition of sodium nitrate at 268°C and its fusion at 297°C. A broad, shallow endotherm, during which a colorless and then a yellow liquid condenses on the sample tube, culminates in ignition. The sodium nitrate-carbon system exhibits the crystalline transition of sodium nitrate, successfully followed by sodium nitrate fusion, and then ignition at 467°C.

DTA curves for the two ternary compositions are shown in Figures 3-17.1 and 3-17.2. The mixture containing magnesium, sodium nitrate, and carbon is very similar to the sodium nitrate-carbon binary mixture; i.e., it ignited at 455°C immediately following the crystalline transition and fusion of the sodium nitrate. The mixture containing magnesium-sodium nitrate-Laminac ignited at 489°C. The first thermal phenomena observed were the

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crystalline transition and fusion of sodium nitrate at 270°C and 299°C, respectively. There was a small, sharp exothermal reaction beginning at 373°C, and another beginning at 450°C, with peak temperatures of 405°C and 485°C, respectively. Ignition occurred as the system was recovering from the second exothermal reaction. These and related results indicate that it is not feasible to write preignition or combustion reactions for the systems containing Laminac due to the complexity of the polymer and the uncertainty of its combustion products.

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CHAPTER 4

VISIBILITY

4-1 INTRODUCTION

In the design and development of military pyrotechnic devices for illuminating a selected area, and for visual signaling when other methods of communication are impractical or impossible, an understanding of human visual performance is important. The complex tasks performed in modern military operations require sufficient light in order that unfamiliar objects can be located and recognized against their backgrounds.

Signaling by methods which depend on sight are commonly used in military tactics, in training exercises, and in evaluation of performance of military items during development programs. These signals derive from packaged units designed to emit smoke, flame, or light, or otherwise to give visual indication of some event, e.g., the marking of a particular spot on the ocean, or to trace the trajectory of missiles or other moving devices. They may be coded by color to convey information relating to different types of events or a sequence of events. For example, a red signal might be used to indicate the arming of a fuze and a green signal to indicate when functioning occurs. Signals for marking purposes can be used to aid in tracking enemy submarines, to allow submerged submarines to make their positions known, to locate tow targets, and to call attention to survivors of air crashes or sinkings.

4-2 VISION

Inasmuch as vision is a sensation recorded by the eye, it is important to consider some of the properties and characteristics of the eye. The functioning of the eye involves a complex of physical, physiological, and psychological factors. Light falling upon the eye acts as a stimulus to produce a sensation which, in the simplest case, is a sensation of brightness.

The eye contains two types of receptors, the rods and the cones. The central portion of the retina, the fovea, is populated exclusively by cones, and is the area of color perception. The region immediately surrounding the fovea is known as the parafovea and contains the rods, which do not recognize colors. The eye has two distinct states—the light-adapted state and the dark-adapted state. The eye is in the light-adapted state when the field luminance is about 10^{-3} candella per square foot, and is dark-adapted at luminances below this. However, the eye is not fully dark-adapted until it has been exposed to the low level of luminance for about 30 minutes. Only two to three minutes are required for the transition for the dark-adapted to the light-adapted state.

In the light-adapted state both the rods and cones are receptive to light. In the dark-adapted state only the parafovea, composed of rods, is active, with the results that color differences are not recognized and that faint signals are best seen when off to a side (looked at "out of the corner of the eye") rather than when looked at directly.

4-2.1 BRIGHTNESS CONTRAST

An object can be distinguished from its background (or from another object) because it has a different color or brightness. It has been shown experimentally that differences in brightness are usually much more important than differences in color. The brightness contrast C is defined by the equation:

$$C = \frac{B - B'}{B'} \tag{4-1}$$

where B is the brightness of the object and B' is the brightness of the background. If an object is not as bright as its background, the brightness contrast is negative and approaches a value of -1 as a limit. When the object is brighter than its background, the contrast may be very large, for ex-

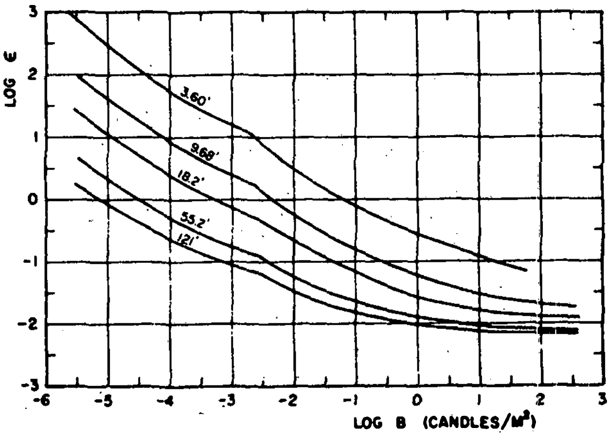

Figure 4-1. Thresholds of Brightness-Contract for 80% Detection for Five Angular Fields (Minutes of Arc)

ample, a bright light on a dark night. The brightness contrast in daylight or in artificially produced white light, where the difference in brightness is due mainly to the amount of light reflected by the object as compared to its background, seldom exceeds a value of 10. If an area has been camouflaged, the brightness contrast may be 0.1 or less.

If the brightness ratio B/B' approaches unity, a stage is reached where an object can no longer be distinguished from its background.

While the threshold contrast varies with each individual, average values as shown in Figure 4-1 depend on the angle which the object subtends at the observer's eye and the mean level of illumination. For daylight conditions, a value of 0.02 is generally accepted as an average value for the threshold contrast or limen.

Visual acuity is often expressed as the reciprocal of this angle in minutes of arc. An acuity value of 1.0 is accepted as a standard for normal vision even though, under ideal conditions, much greater detail can be resolved.

Up to about one-fifth second, the photochemical reciprocity law applies and the product of the illumination times the duration is a constant. It has been demonstrated in threshold measurements of visual performance that, in those cases where the duration is longer than one-fifth second (as is true for most cases of interest in pyrotechnics), this is not applicable.

4-2.2 OVERALL CONTRAST

The overall contrast C_o between an object and its background is approximately:

$$C_o = (C_b^2 + C_c^2)^{1/2} \qquad (4\text{-}2)$$

where C_b is the brightness contrast, and C_c is the achromatic brightness contrast, equivalent to the chromatic component of the contrast. As chromatic components of contrast are rarely over 25 percent of the total and are invariably associated with brightness contrasts greater than 25 percent, visibility, under field conditions, depends primarily on the brightness contrast. This is especially true for objects viewed at a distance since the scattered light from all sources tends to still further dilute the color contrast. Where brightness contrasts are limited, as in the case of signal flags or panels, color difference may increase visibility. However, at or near the limit of visibility, the hues of chromatic target are not perceptible. This is particularly true for violet, blue, green, and yellow stimuli. Orange, red-purple, and red appear reddish or brownish under these circumstances.

4-3 ATTENUATION OF CONTRAST

The apparent contrast (both brightness and achromatic) between an object and its background is reduced when viewed through a medium which scatters and absorb light. For a homogeneous medium like the atmosphere, containing both the observer and the object, the amount of contrast reduction is governed by the balance between the light transmitted from the object, and its background, and the space light contributed by the intervening medium. If the medium is stratified, as would be the case when a smoke screen is located between the object and the observer, reflection due to multiple-scattering may still further reduce the apparent contrast.

In general, if the inherent brightness contrast between two objects, or of an object and its background, is given by Equation 4-1, the apparent brightness contrast C_x, when viewed at a distance, will be:

$$C_x = \frac{(B - B')e^{-\beta x}}{B'e^{-\beta x} + G} \qquad (4\text{-}3)$$

where B is the brightness of the first object and B' is the brightness of the second object or the background, β is the scattering coefficient, x is the distance, and G is the glare scattered and reflected by

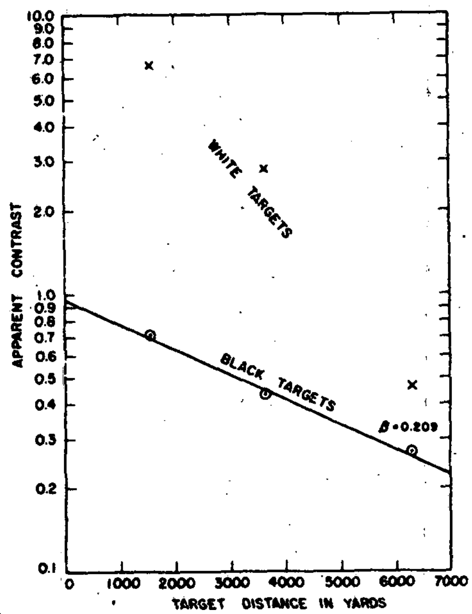

Figure 4-2. Apparent Contrast as a Function of Distance

a cloud in the same direction as the light from the object. The object will be visible only if the apparent contrast is greater than the threshold contrast or "limen" for the particular total illumination level.

4-3.1 ATTENUATION OF CONTRAST BY THE ATMOSPHERE

The apparent contrast between two distant objects, or a distant object and its background, is reduced as shown in Figure 4-2 when they are viewed through an atmospheric aerosol. This reduction in apparent contrast limits the maximum distance at which targets and signals can be seen.

The most general expression for the reduction of contrast by the atmosphere is:

$$C_{\overline{R}} = \frac{B}{B'} Ce^{-\beta\overline{R}} \qquad (4\text{-}4)$$

$C_{\overline{R}}$ is the apparent contrast between two objects, or an object and its background at the effective (slant) range $\overline{R}$; C is their inherent contrast; B is the brightness of the object; B' is the brightness of the background (or second object); and β is the scattering coefficient.

If the atmosphere is optically homogeneous, i.e., the apparent brightness of the sky is not changed by moving toward or away from the horizon, this equation reduces to:

$$C_x = Ce^{-\beta x} \qquad (4\text{-}5)$$

where C_x is the apparent contrast at a distance x.

The meteorological range, the horizontal range for which the transmission of the atmosphere is two percent, is given by:

$$X_R = \frac{-1}{\beta}\, ln\, 0.02 - \frac{3.912}{\beta} \qquad (4\text{-}6)$$

The meteorological range is the distance at which a large black object, which has an inherent contrast of —1, can just be recognized against a daytime sky. Visibility, as normally reported, is about ¾ the meteorological range. The meteorological ranges for typical weather conditions are given in Table 4-1.

If the object is viewed against backgrounds other than the sky, the expressions are more complicated. The apparent contrast at an effective distance $\overline{R}$ of a target against any background is given by:

$$C_{\overline{R}} = \frac{C}{1 + (B_H/B')(e^{\beta\overline{R}} - 1)} \qquad (4\text{-}7)$$

where C is the inherent contrast between the object and its background, B_H/B' is the ratio of the brightness of the horizon sky in the direction of the object to that of the background, and β is the scattering coefficient. If the ratio B_H/B' is one, this equation reduces to the equation applicable to the visibility of an object against the horizon sky.

The calculation of the visibility of an object, when viewed from above, is complicated due to the stratification of the atmosphere. If this stratification can be considered continuous, the scattering coefficients will vary regularly and in a predictable manner. Normally, however, this is not true, and the effective optical range $\overline{R}$ is taken as the horizontal distance containing as many scattering particles as are found in the slant path R. The

TABLE 4-1
METEOROLOGICAL RANGE FOR TYPICAL WEATHER CONDITIONS

Weather	*Daylight Visual Range, V*	*Attenuation Coefficient, B, Per Sea Mile*	*Transmission, Per Sea Mile*
Dense fog	50 yards	156.4	0.02^{40}
Thick fog	200	39.1	0.02^{10}
Moderate fog	500	15.6	0.02^{4}
Light fog	1000	7.82	0.02^{2}
Thin fog	1 sea mile*	3.91	0.02
Haze	2	1.95	0.141
Light haze	3	1.30	0.272
	4	0.98	0.376
Clear	5	0.782	0.457
	6	0.651	0.521
	7	0.559	0.572
	8	0.488	0.614
	9	0.434	0.640
Very clear	10	0.391	0.676
	11	0.356	0.700
	12	0.326	0.723
	14	0.279	0.756
	16	0.244	0.783
Exceptionally clear	18	0.217	0.805
	20	0.196	0.823
	24.1	0.162	0.85
	37.1	0.105	0.90
	71.8	0.051	0.95
Theoretically pure air	167	0.0234	0.976

*1 sea mile equals 1.15157 statute miles or 6080 feet.

effective optical range $\overline{R}$ is related to actual path by:

$$\overline{R} = \frac{21{,}700}{\sin\Theta}\left(1 - e\left[\frac{-R\sin\Theta}{21{,}700}\right]\right) \quad (4\text{-}8)$$

where Θ is the angle that the slant path R makes with the horizontal. Plots of this equation for various values of Θ, applicable for intermediate values of the slant range R, are presented in Figure 4-3. The values of the true altitude are indicated by the dashed lines on this diagram.

4-3.2 OBSCURATION OF VISION BY ARTIFICIAL SMOKE CLOUDS

The influence of artificially produced smoke clouds on visibility is complicated by the fact that the smoke may occupy only a relatively narrow region between the target and the observer. Under these circumstances, the intensity of illumination may vary greatly depending on the relative location of the object, the observer, the smoke cloud, and the source(s) of illumination, so that the quantity of smoke required for obscuration is a highly variable quantity. Because of the complicated way in which the incident light is scattered as a function of angle and because of multiple scattering, the degree to which light will penetrate a cloud can only be approximated. While a major fraction of the light scattered by particles near the optimum size for a screening smoke is scattered in the forward direction, some light is

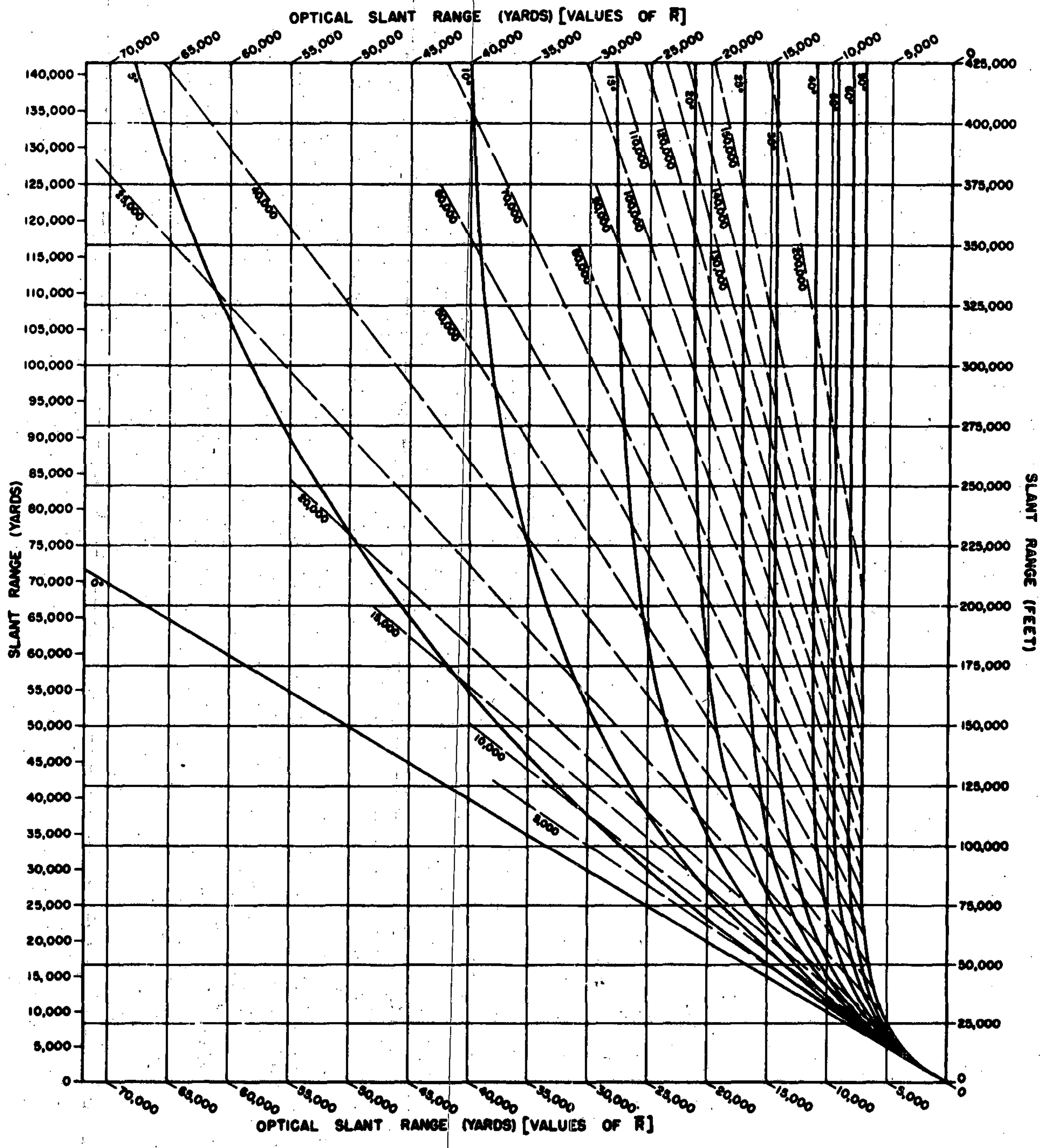

Figure 4-3. Optical Slant Range Diagram for the Optical Standard Atmosphere

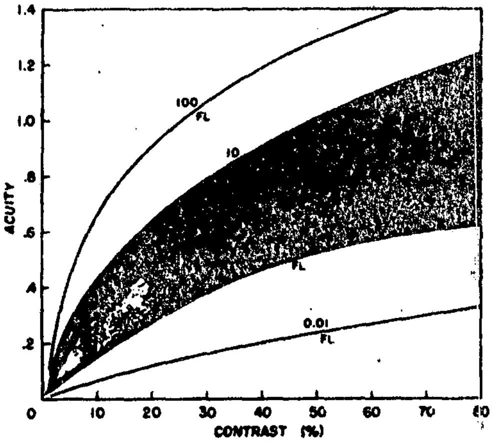

Figure 4-4. Brightness Requirements as a Function of Acuity and Contrast

scattered in the backward direction. If a cloud is of a sufficient depth and concentration, essentially all of the light not absorbed by the cloud will return to and be scattered from the same side of the cloud that it entered and the cloud will behave as a white body diffusely reflecting the light which falls upon it.

For a thinner cloud, part of the incident light will penetrate to the target and background. The apparent contrast of the target against its background, in this case, is:

$$C_{\bar{R}} = I_o(1-f)(M-M')e^{-\beta\bar{R}} \qquad (4\text{-}9)$$

where I_o is the effective intensity of the incident light, M is the reflectivity of the target, M is the reflectivity of the background, β is the scattering coefficient, $\bar{R}$ is the effective distance from the target to observer, and f is the fraction of incident light which penetrates to the target. The amount of light reaching the target, as well as the attenuation of the contrast between the target and its background, depends on the number of scattering particles which, in turn, depends on the product of the concentration of the smoke and the thickness of the cloud.

The effectiveness of a smoke screen also depends on the relative location of the smoke target background and light source. The effect of these changes in relative locations is complicated, and has not been worked out in detail. In general, anything which tends to increase the effective brightness of the smoke cloud, as well as anything that tends to reduce the illumination on the target and background, will increase the effectiveness of a smoke screen.

4-4 VISIBILITY OF TARGETS AND SIGNALS

The distance at which a ship, low-flying aircraft, shoreline, or other target, and also the distance at which a signal can be seen against its background depends mainly on (1) the perceptual capacity of the observer at the level of brightness to which his eyes are adapted and (2) the apparent contrast between the target and its background and the angle it subtends at the eye of the observer. The angle, subtended by a target area, depends on the size and shape of the object. For a circular target at a distance of X yards, the angle α subtended by a circular target A square feet in area, is:

$$\alpha = \frac{1293\sqrt{A}}{X} \text{ minutes of arc} \qquad (4\text{-}10)$$

As the apparent contrast is also a function of the distance, calculations intended to determine the range at which a target or signal can be sighted must be a series of successive approximations. In addition, because of the curvature of the earth, the target or signal, or the observer, must be elevated for sighting long distances. The geometrical range for various heights is given by:[2]

$$X = 1.325(H + h) \qquad (4\text{-}11)$$

where H is height of target or signal in feet, h is height of observer in feet, and X is the distance in miles.

4-4.1 VISIBILITY OF TARGETS UNDER ARTIFICIAL ILLUMINATION[3]

It is impractical to require that normal visual acuity (resolution of one minute of visual arc) be maintained when the illumination is provided by pyrotechnic flares since there is a practical limit to the intensity. The intensity should be such that targets, having a size and a contrast with the background that is typical of field conditions, can be readily located and recognized. Intensities greater than this minimum are excessive. As shown in Figure 4-4, illumination levels between 0.1 and 10.0 foot-lamberts (FL)*, which can be obtained

* NOTE 1 millilambert ≃ 1 foot-lambert.

TABLE 4-2
REFLECTANCE VALUES (IN PERCENT) OF VARIOUS TERRAIN FEATURES AND BUILDING MATERIALS

Object	*Wavelength in Microns*						
I. Natural Terrain							
a. Soils:	*0.4*	*0.5*	*0.6*	*0.7*	*0.8*	*0.9*	*1.0*
Dry yellow earth	8	16	37	55	69	76	82
Wet yellow earth	5	9	25	42	58	67	76
Dry sand	18	28	37	45	52	56	58
Wet sand	10	15	26	32	37	41	43
Dry red earth	8	8	20	28	33	35	37
Wet red earth	6	6	12	28	22	24	25
Dry brown earth	8	11	15	19	21	23	24
Wet brown earth	4	6	11	14	15	17	19
Dry loam	8	12	18	20	20	21	22
Wet loam	5	6	7	9	10	11	11
b. Vegetation:							
Grass	6	8	10	13	55	67	70
Evergreens	3	4	7	6	24	24	24
Straw	7	15	24	33	39	44	46
Dead grass	7	13	20	26	31	35	37
Dead brown leaf	6	9	11	27	43	51	69
Dead yellow leaf	6	10	23	39	45	48	51
c. Terrain as seen from 4,000 feet:							
Green field					4	7	10
Brown field					3	4	5
Yellow-green vegetation					5	8	15
Light sand					12	16	21
Sandy ground					8	12	14
Wet mud					5	8	9
Mud covered with water					4	7	6
Pond water					3	2	1
Water with suspended material					3	4	5
Dark volcanic rock					6	6	7
Black asphalt runway					4	4	4
II. Building Materials							
a. Paints:				4	4	4	4
Black				6	6	11	12
Earth brown				9	15	45	47
Earth yellow				6	7	19	21
Earth red				15	24	42	43
Sand				16	21	37	41
Desert sand				7	9	16	16
Field drab				4	7	11	9
Olive drab				4	6	7	5
Forest green							

TABLE 4-2 (cont'd)

Object	*Wavelength in Microns*						
II. Building Materials (Continued)							
a. Paints (Continued):	*0.4*	*0.5*	*0.6*	*0.7*	*0.8*	*0.9*	*1.0*
Dark green				5	7	6	6
Sky gray				33	40	48	45
Haze gray				35	33	24	24
Blue gray				25	27	25	23
Ocean gray				22	20	13	13
Sea gray				14	13	12	10
Slate gray				9	10	9	7
Sea blue				7	6	5	4
Red				5	5	25	75
b. Materials:							
Concrete tiles (uncolored)		28	35	37	37	37	37
Concrete tiles (black)		9	9	9	9	9	9
Slates (silver gray)		19	20	21	21	21	21
Slates (blue gray)		12	13	14	14	15	16
Slates (dark gray)		10	12	12	12	11	10
Clay tiles (Dutch light red)		23	51	64	66	66	65
Clay tiles (red)		11	28	35	37	40	40
Clay tiles (red-brown)		13	25	30	33	40	41
Dark concrete	13	16	20	17			
Light concrete	25	32	37	38			
Galvanized iron	23	26	27	25			
Dirty galvanized iron		9	9	9	9	9	9
Aluminum	45	49	52	53			
Steel	29	31	34	35			
Granite	10	15	20	22			
Asbestos cement		35	43	45	44	41	37
Weathered wood	9	11	8	10			
Weathered asphalt		9	10	11	11	11	11
Basalt	5	6	7	6			

quite readily with pyrotechnic illuminants, should be adequate to detect and identify objects subtending approximately 5 minutes of visual arc against a terrain background, provided the contrast is greater than 0.1. When the target and its background are illuminated by the same light source, this contrast will (as is true for daylight illumination) depend on the reflectance values for the target and background. Values for typical materials which might be found in the field are given in Table 4-2.

4-4.2 VISIBILITY OF SIGNALS

The requirements for visibility of a signal vary considerably from one application to another. It is not always possible, nor necessary, to provide a signal which is visible at extreme ranges. However, it is desired that a signal produce the maximum visual effect over as long a distance as possible and, in some cases, for as long a period as possible. In addition, it is often necessary to modify signal performance to meet practical size and weight restrictions. These restrictions are

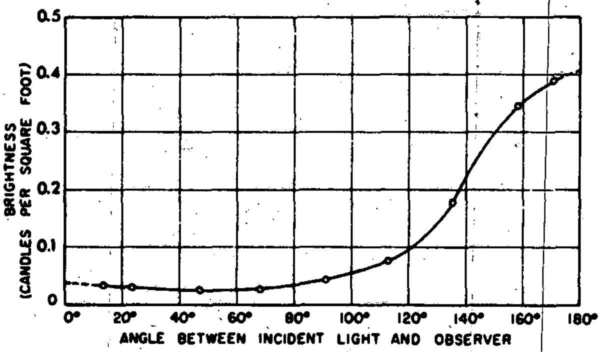

Figure 4-5. Effect of Direction of Illumination on the Luminance of a Smoke Column

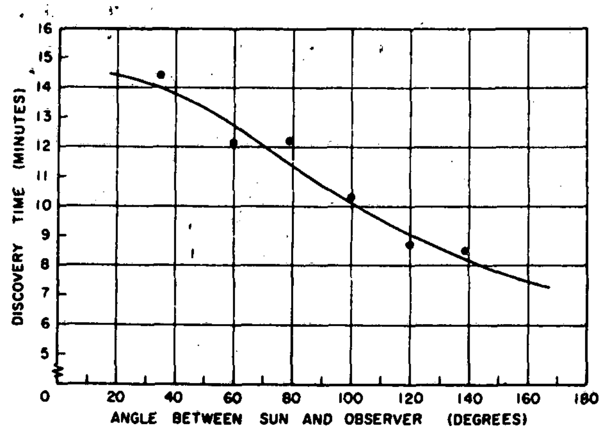

Figure 4-6. Effect of Relative Direction of Sun and Smoke on Time of Discovery

extremely important for signals carried aboard aircraft or submarines.

4-4.2.1 Visibility of Smoke Clouds

The visibility of a relatively small dense smoke cloud, such as would be produced as a signal, depends on the ability of the smoke particles to scatter light, or reflect by multiple scattering, in the direction of the observer. Factors which determine, to a large extent, the visibility of a smoke cloud include: (1) illumination of the smoke cloud, and (2) contrast of the cloud against a background.

The effective brightness of the cloud depends on the relative location of the observer and cloud, as well as the intensity and direction of the incident light. This effect is indicated in Figure 4-5 for a relatively dilute, laboratory smoke column. These results, due to the tendency toward forward scattering, indicate that a smoke column is many times as bright in the direction of the sun as it is opposite to the sun. The effect of the relative direction of the sun and smoke is also illustrated in Figure 4-6 where, as expected, the time of discovery is the least when the relative positions result in a maximum cloud brightness. Color of a relatively dense cloud results from multiple scattering and absorption. The color intensity in a dilute cloud may be less because of the reduced multiple-scattering efficiency. If the particles making up the cloud are the wrong size (too small, normally), the color produced may be changed and/or suppressed. The apparent color of the cloud will change with distance and, near the limit of visibility, will be effectively the same color as the horizon.

4-4.2.2 Visibility of Light Sources

Factors which influence the visibility of a light source are essentially the same as for any other object. The visibility of an illuminated visual angle of approximately one degree or less is dependent principally upon the total light emitted by the area. For a steady point source:

$$F = \frac{C}{X^2} = 3.5 \times 10^{-9} H^{1/2} \text{ lumens/cm}^2 \qquad (4\text{-}12)$$

where F is the threshold value of flux density (in lumens per square centimeter), C is the threshold intensity of the source (in candles), X is the distance from source to observer (in centimeters), and H is the background brightness (in candles per square centimeter). The illumination produced at the observer's eye is reduced because of atmospheric attenuation in accordance with the following equation:

$$E_x = \frac{I_o}{X^2} \exp\left[-3.912 \left(\frac{X}{X_R}\right)\right] \qquad (4\text{-}13)$$

where I_o is the intensity of the source and X_R is the meteorological range. This equation is valid only when X is large enough that the light may be considered as a point source. The maximum angular size of the light source, which can be considered as a point source, varies with the adaptation brightness as given in Table 4-3.

TABLE 4-3
MAXIMUM ANGULAR SIZE OF LIGHT SOURCE AS A FUNCTION OF ADAPTATION BRIGHTNESS

Adaptation brightness (*foot-lamberts*)	*Maximum angular size* (*minutes of arc*)
1,000	0.708
100	0.708
10	0.750
1	0.891
10^{-1}	1.30
10^{-2}	2.82
10^{-3}	6.68
10^{-4}	8.55
10^{-5}	15.0

A flashing point-source light, where the flashes are of short duration (less than 0.2 second), must have, in general, a higher candlepower than a steady light in order to be seen. It has been found that the threshold intensity F, required for visibility of a light of duration t_o seconds, is given by:[4]

$$Ft_o = F_s\,(t_o + 0.21) \qquad (4\text{-}14)$$

where F_s equals the threshold intensity of a steady light. Thus, when a flash lasts several seconds so that 0.21 is negligible, the threshold is the same as for steady light. However, as shown in Table 4-4, for small values of t_o, where F will be larger than F_s, this is no longer true. These ratios are not changed greatly for candlepowers up to 50 times threshold for flash durations from 0.05 second up to 1.0 or 2.0 seconds.

For situations in which it is not known where a flash will appear in the field of view, the finding time is quite important. The two variables of major importance in the conspicuity (short finding time) of a flashing light of a candlepower well above threshold intensity are: (1) the time interval between flashes T, and (2) the duration of each flash t_o in seconds. A flashing light is most conspicuous when T lies between 0.5 and 1.0 second and t_o is between 0.25 and 0.75 second.[3] Decreasing T or increasing t_o/T increases the finding time because of reduction of flicker. If t_o is below 0.5 second, the average finding time is increased (for values of T as low as 1.0 second) because of the lower visibility of short flashes (according to Blondel and Rey). If T is greater than 1.0 second, the finding time is also longer because the eye may pass over the light location during the off interval. It was found that a light of ten times threshold intensity was almost always located at the first flash while three flashes were needed if the light were only five times the threshold.

The effect of selective transmission by some types of atmosphere is also important when considering colored lights. Table 4-5 indicates the magnitude of selective absorption of components of sunlight by the atmosphere.

4-4.3 ESTIMATION OF VISIBILITY

The estimation of visibility can be simplified by the use of nomographic visibility charts prepared for this purpose. A chart for circular targets, which has been adapted from the more complete charts available, is given in Figure 4-7. To use this chart for determining visibility along a horizontal path, a straightedge is laid across the chart in such a manner that it connects the value of the inherent contrast between the object and its background with the value of the sky-background brightness ratio (this sky-background ratio is unity if the background of the target is the horizon sky), extended to intersect the zero liminal target distance line. The straightedge is then relocated so that it connects this point with the

TABLE 4-4
VISIBILITY OF FLASHING LIGHT COMPARED TO STEADY LIGHT

Flash Duration, seconds	*Ratio of Flashing Light to Steady Light*
1.0	1.2
0.5	1.4
0.4	1.5
0.3	1.7
0.2	2.0
0.1	3.1
0.05	5.2
0.025	9.4
0.01	22.0

TABLE 4-5
ABSORPTION OF SUNLIGHT BY ATMOSPHERE

Wavelength, Angstroms	*Percentage Transmitted*
4000	47.5
4500	55.3
5000	62.4
6000	68.2
7000	75.6
8000	80.1

These figures represent the relative transmission for the different wavelengths during the day under average clear conditions with the sun at the zenith, and they may vary greatly under other conditions. It must be remembered that a light signal can be seen at a much greater distance than the distance at which its color can definitely be distinguished.

value for the meteorological range. The intersection of the straightedge and the curve for the correct general illumination level locates the liminal target distance.

The procedure for estimating the visibility for slant paths is somewhat more complicated, especially if the atmosphere is stratified. If no optically dissimilar strata are present, the optical slant range can be determined in the same manner as the visual range, along a horizontal path. The actual slant range can then be approximated by the use of Equation 4-18 or Figure 4-3. Because the slant range is normally greater than the optical slant range, the effective area of the target is less than its actual area and the predicted slant range will be high. A better value can be obtained, if an effective area $\bar{A}$ can be calculated, for targets which subtend a small angle at the observer's eye, by the equation:

$$\bar{A} = \left(\frac{\bar{R}}{R}\right)^2 \quad (A \sin \Theta) \qquad (4\text{-}15)$$

where $\bar{R}$ is the first approximation of the optical slant range estimated by use of the nomograph, R is the corresponding slant range for a sighting path which makes an angle Θ with the ground, and A is the area of the target. This value for $\bar{A}$ is now used to calculate a better value for the optical slant range $\bar{R}$ and corresponding slant range R.

The nomographs are also useful when stratification of the atmosphere causes an effective discontinuity in the meteorological range-altitude rela-

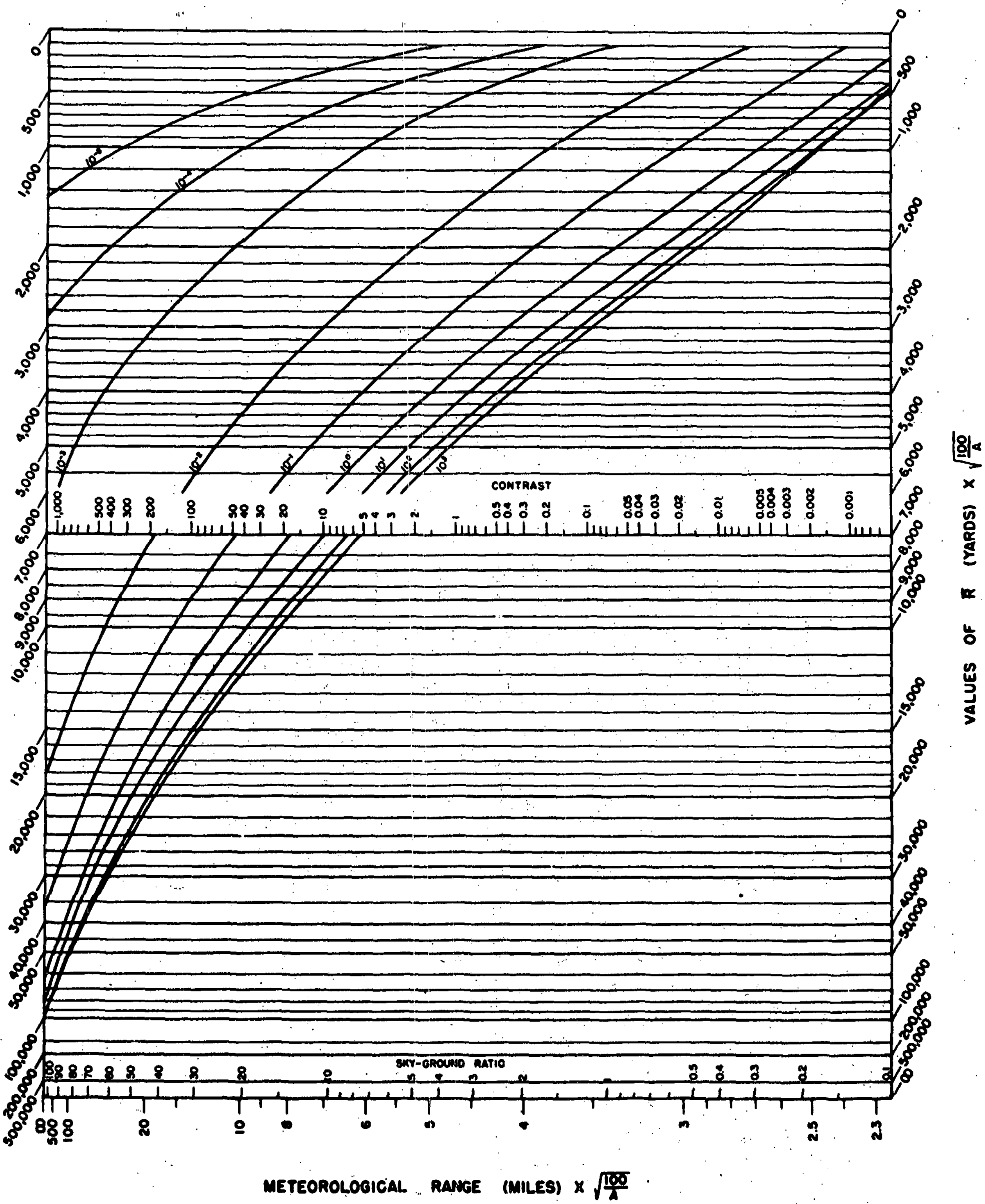

Figure 4-7. Visibility Nomograph

TABLE 4-6
SKY BRIGHTNESS

Ambient Condition	*Brightness, millilamberts*
Hazy*	10,000
Clear	1,000
Light Overcast	100
Heavy Overcast	10
Twilight	1
Deep Twilight	0.1
Full Moon	0.01
Quarter Moon	0.001
Starlight	0.0001
Overcast Starlight	0.00001

* The maximum brightness condition which is likely to be encountered is that of the sky on a slightly hazy day at noon.[6]

TABLE 4-7
SKY-GROUND RATIO

Sky Condition	*Ground Condition*	*Sky-Ground Ratio*
Overcast	Fresh Snow	1
Overcast	Desert	7
Overcast	Forest	25
Clear	Fresh Snow	0.2
Clear	Desert	1.4
Clear	Forest	5

tionship. Let it be assumed, for example, that there is a ground haze which has a top at 5000 feet, and that the meteorological range is five times greater above the haze boundary than below it. For this type of visibility problem, a line is constructed on the optical slant range diagram, Figure 4-3, from the origin to the intersection of the curve for the desired viewing angle Θ, with the dashed line representing the true altitude of 5000 feet. A second curve (which has five times the slope of the original curve) is drawn starting at this point. The relationship between $\bar{R}$, the optical slant range, and R, the slant range, follows the resultant curve. If the actual boundary of the ground haze is diffuse, the sharp change in slope can be rounded off. Because of the problems involved, the estimation of slant ranges is less satisfactory than the estimation of horizontal range. Where experimental values are not available, typical values for the sky brightness are given in Table 4-6 for various ambient conditions. Typical values for the sky-ground ratio are given in Table 4-7.

It is to be noted that the nomograph predicts a distance at which the target is liminally visible. If the contrast value is divided by two before using the nomograph, the result obtained is the sighting range, the distance at which the object can be seen with threshold confidence. For the object to be easily seen, the contrast values should be divided by at least four.

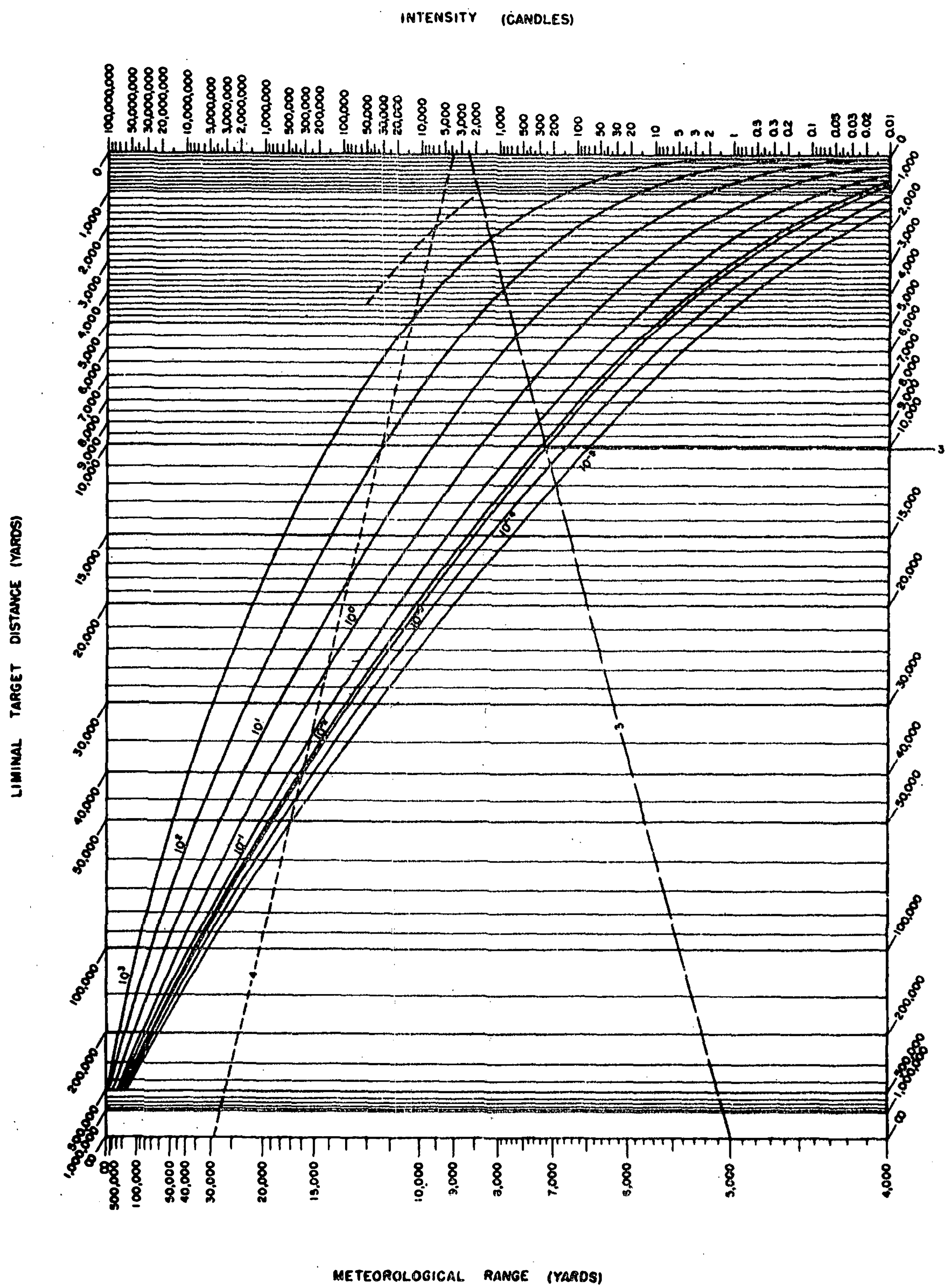

Figure 4-8. Visibility Nomograph for Signal Lights

TABLE 4-8
INCREASE IN ILLUMINATION REQUIRED FOR POSITIVE RECOGNITION

Field Factor Applied to Threshold Candlepower	*Detectibility of Light Source*
1	Light source difficult to find even if location is known.
2.5-5	Light source moderately difficult to find if location is approximately known and observer is on steady platform and has long time for search.
5-10	Light source easy to find under circumstances above.
20-30	Light source easy to find under reasonable circumstances at night, for example, search field no greater than 100 degrees, observer can give his full attention. Difficult to find in daytime unless observer knows where to look.
100-150	Light source can be found under strenuous circumstances at night, and under most circumstances in the daytime if the search field is not too large.

Square objects are as visible as circular objects of the same area. Objects of other shapes are, in general, less visible.

Figure 4-8 is a visibility chart for predicting the range at which signal lamps and other point sources of light will be liminally visible. To use this chart, a straightedge is placed across the chart so that it connects the meteorological range with the intensity of the light source. The intersection of this straight line with the curve for the proper sky brightness level is the liminal target distance. For signaling purposes at this distance where positive recognition is required, the illumination value should be increased as indicated in Table 4-8.

4-4.4 ILLUSTRATIVE EXAMPLES

1.a. The distance at which a uniform circular target of 100 square feet with a brightness of 10 foot-lamberts will be liminally visible on a clear day, when the meteorological range is 20,000 yards, can be estimated in the following manner:

As sky brightness on clear day is approximately 1000 foot-lamberts, the contrast of target against sky as background is:

$$\frac{10\text{-}1000}{1000} = -.99$$

The sky-ground ratio is 1.0 since the object is being viewed against sky. To obtain liminal target distance from nomograph, connect (as shown in Figure 4-9) with a straightedge a sky-ground ratio of 1.0 with a contrast of 0.99 and mark intersection of straightedge with the zero liminal distance line. Connect this point with the meteorological range of 20,000 yards. The liminal target distance is read where this straight line intersects

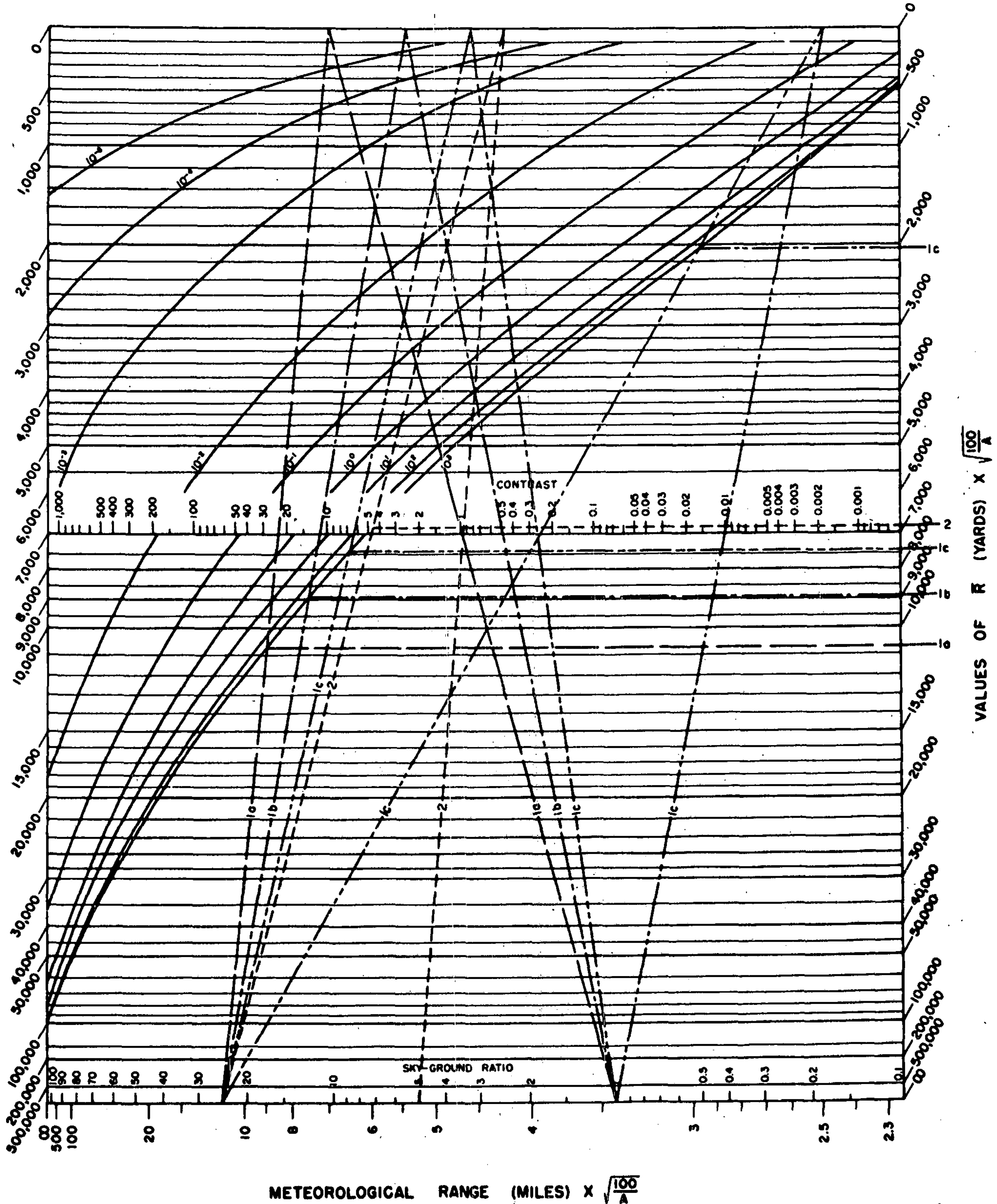

Figure 4-9. Visibility Nomograph Showing Calculation

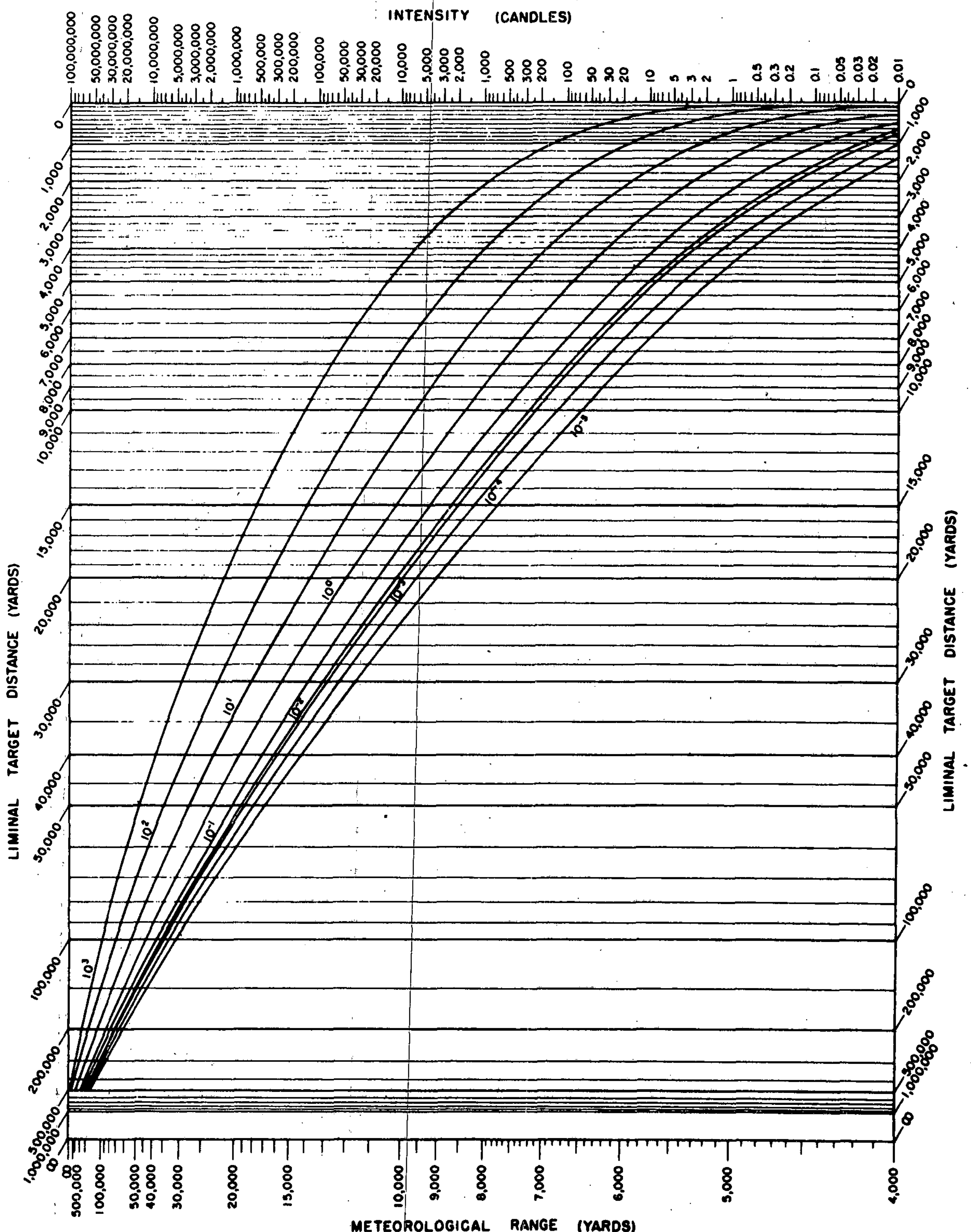

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Figure 4-10. Visibility Nomograph for Signal Lights Showing Calculation

with the curve for the ambient illumination, 10^3 foot-lamberts. The liminal target distance, in this case, is approximately 11,000 yards.

1.b. The sighting range is calculated in the same way except that the effective contrast is:

$$\frac{0.99}{2} = 0.495$$

The sighting range is approximately 9,000 yards.

1.c. The distance at which this target could be seen easily under field conditions:

In order for a target to be seen easily, the contrast values must be divided by at least 4.0. Under difficult field conditions, the contrast value might have to be divided by a number as large as 100. The effective contrast range, therefore, is

$$\text{from } \frac{0.99}{4} = 0.25, \quad \text{to } \frac{0.99}{100} = 0.01$$

and the distance at which the target could be seen easily might be as low as 2,000 yards (2,000 to 7,500 yards).

2. The distance at which the same target would be liminally visible under the same conditions, if it were to be observed against a background having a brightness of 200 foot-lamberts can be calculated. (Since the target and background are both illuminated by the same light source, the reflectance of the background is approximately 20 times that of the target.) In this case, the sky-ground ratio is $1000/200 = 5.0$, and the contrast is:

$$\frac{10\text{-}200}{200} = -0.95$$

As indicated in Figure 4-9, the determination of the liminal range is the same as outlined for Example 1.a. The liminal distance under these conditions is approximately 6,900 yards. The sighting distance and the distance at which the target could be seen easily would also be calculated in the same manner as illustrated for Example 1.b. and 1.c.

3. The distance at which a signal having an intensity of 2,500 candles would be liminally visible on a foggy night when the meteorological range is 5,000 yards, can be estimated using the signal light nomograph. A straightedge is placed across the nomograph for signal lights so that it connects the meteorological range, 5,000 yards, with the candlepower, 2,500 candles, as shown in Figure 4-10. The liminal distance is given by the intersection of this line with the curve for the illumination level 10^{-3} foot-lamberts.

4. The intensity required for a spotting charge to be seen at 2,000 yards over water and toward a rising sun on a clear day, can be estimated by use of the signal light visibility nomograph. Under these conditions, the illumination level would approach 10^4 foot-lamberts. The meteorological range is assumed to be approximately 30,000 yards, a clear day. The intensity required for a light source to be liminally visible under these conditions is obtained from the signal light nomograph by connecting the meteorological range, 20 miles, with the point of intersection of a liminal target distance of 2,000 yards, and the curve for the general illumination level (approximated by dotted curve on Figure 4-10). The intersection of this line with the zero liminal distance line gives the candlepower required, about 4,000 candles. In order to be seen readily under these field conditions, the intensity values should be multiplied (see Table 4-8) by 100 to 150, yielding a required intensity of 4×10^4 to 6×10^4 candles.[6]

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CHAPTER 5

PRODUCTION OF HEAT

5-1 HISTORICAL SUMMARY[1,5,6,7,8]

The systematic use of incendiaries extends back into ancient times when practically any readily combustible material was used for both offensive and defensive operations. Incendiary-type compositions were used in fireballs, pots, or crude bombs and hurled against the enemy by means of a catapult, or as headings for slings and bow arrows, and other purposes. Some of the earlier combustible materials used included oil, pitch, sulfur, resinous woods, and straw. "Greek fire," an incendiary mixture which probably contained readily flammable substances such as pitch, resin and petroleum, along with quicklime and sulfur, was used in the 17th century against ships, tents, barricades, cities, and personnel. It was especially valuable as an incendiary because it was difficult to extinguish since as water reacted with the quicklime and also spread the petroleum. These types of incendiaries were of definite value in all of the wars fought during the Middle Ages and their importance was not diminished until gunpowder was introduced in the 15th century.

During the 16th, 17th, and 18th centuries, the basic ingredients in incendiary mixtures continued to be sulfur and saltpeter to which were added a number of flammable materials such as resin, pitch, tallow, beeswax, linseed oil, and turpentine. For many years the recognized incendiary projectiles were known as "carcasses." In their earliest form they consisted of cylindrical bags or containers of canvas coated with pitch and bound with iron hoops. The name was suggested because of the likeness of these iron hoops to the ribs of a corpse. Later, their shape became spherical; however, their filling remained the same—a mixture of saltpeter, sulfur, resin, antimony sulphide, and tallow—until carcasses became obsolete toward the end of the 18th century.

Rockets with incendiary charges were employed by the British in the American Revolution as well as by the armies involved in the many European conflicts of the 19th century. The United States Army had incendiary items of ordnance issue in the early part of the 19th century. During the American Civil War, the incendiary projectiles developed by the Union Army and fired against Vicksburg, Charleston, and Petersburg were of limited value. A flammable liquid was also developed which could be used with a flame thrower. These flame throwers reached Bermuda Hundred, Virginia, early in 1865, and may have been used in later battles of the Civil War.*

In general, however, from the beginning of modern times down to World War I, incendiaries were not extensively used due to the increase in battle distances, resulting from the introduction of firearms. In addition, the defensive use of armor and earthworks left little material that would burn on the battlefields. These problems were not solved until the advent of the World War I.

While both the French and German Armies had developed incendiary artillery projectiles before World War I, these projectiles were not used to any extent in the early days of the war, probably because they were ineffective against military targets. The first incendiary munitions used in this war evidently were incendiary bullets and antiaircraft artillery projectiles directed against observation balloons, and flame projectors against ground troops. These devices, along with incendiary bombing from aircraft, were first used by the Germans in 1915.

Intensive research and development programs were established by all the principal belligerents in order to obtain improved incendiary munitions. White phosphorus was effective against

*W. D. Miles, "The Civil War," Part I, *Chemistry and Engineering News*, Vol. 39, No. 14, April 3, 1961.

readily combustible material such as balloons. It was also very effective against personnel as it produced painful burns and hence caused a demoralizing effect far in excess of the casualties produced. Thermite and modified thermite mixtures were widely employed, especially in connection with an additional incendiary material such as "solidified oil." Other mixtures containing an inorganic oxidizer such as potassium or barium nitrate, barium or lead oxide, or potassium chlorate, and a fuel such as carbon, sulfur, magnesium, aluminum, or organic combustibles, were used in small arms incendiary bullets and with less success in drop bombs.

Solid oil (oil mixtures solidified with colloidal additives) and flame projector liquids consisting of a heavy viscous oil or tar and a more fluid and flammable liquid were also developed but saw only limited use during the war.

In spite of the tactical and strategic possibilities associated with the use of aerial incendiary bombs, only a limited amount of the development work on incendiary munitions was directed toward design of improved munitions of this type. Two general types of aerial incendiary bombs were developed. The first was the relatively large bomb filled with an incendiary mixture, often thermite and solid oil, designed to penetrate and set fire to buildings and heavy construction. The second was the scatter type of incendiary bomb which consisted of incendiary units in a large bomb, or a cluster of small bombs (the latter being the more successful of the two techniques), to start fires over a relatively large area.

The increasing use of military aircraft resulted in an increased interest in small arms incendiary ammunition since the employment of incendiary ammunition was considered to be one of the better ways for destroying aircraft. The first small arms round designed for air-to-air combat was probably the British Pomeroy projectile with a kieselguhr dynamite filler which had both high explosive and incendiary functions, and was very effective against German airships. The earliest incendiary small arms projectile used by the United States, adapted from a British design, employed phosphorus as the incendiary material.

In the period between the two World Wars, only a limited amount of research and development was performed on incendiary munitions in the United States. The white phosphorus filling for caliber .30 incendiary ammunition was replaced with a tracer composition. Development work on incendiary compositions was actively resumed in the United States in 1936.

General interest in small arms incendiary ammunition was renewed during the early years of World War II. The DeWilde-Kaufman bullet, designed in Switzerland by 1939, represented a major step forward in the development of small arms incendiary ammunition in that it would function as desired against realistic targets. To eliminate the serious manufacturing and handling problems associated with this design, it was modified by British scientists to use the U.S.-developed IM-11 incendiary mix. Modifications of the British design were made later by the United States Ordnance Department to improve functioning characteristics and to adapt the design to manufacture by mass production techniques. These modifications, including some changes in the incendiary composition, resulted in the U.S. M1 Incendiary Projectile which played an important role in winning the Battle of Britain by defeating the German air attacks. The development of modified incendiary ammunition, including armor-piercing incendiary ammunition, was started in 1943; however, only a small quantity of these items had been produced by the end of the war.

In the Battle of Britain, the Germans used a 1-kilo magnesium bomb against British cities with great effectiveness. A very effective 4-pound magnesium bomb had been developed by the British; however, the United States did not as yet have a satisfactory incendiary bomb. As a consequence, the British MK-III magnesium bomb was redesigned for mass production. A 4-pound thermite bomb was developed as a substitute for the somewhat superior magnesium bomb and was used in General Doolittle's historic raid on Japan in April 1942. A small 2-pound magnesium bomb was also developed and when used in clusters was considered to be more effective against urban German targets than the heavier incendiaries which had been developed for industrial targets. They were also successful against Japanese industrial targets but

penetrated too far to be highly effective against Japanese dwellings.

The development of a small petroleum incendiary bomb was started and led to the development of the 6-pound napalm bomb which was used with spectacular success in the strategic bombing of Japan. Other petroleum incendiary mixtures were developed, including the IM mixture which contained finely divided magnesium. Against both Europe and Japan, incendiary bombs proved to be very effective weapons, especially when approximately one-fifth of them contained explosive charges to discourage fire fighters.

Flame throwers were first used in the Pacific theater on Corregidor by the Japanese against American troops who were not equipped with the weapon. Due to its proven effectiveness and the development of napalm, it was soon used by the United States for combat operations in all theaters of operation, either as a portable unit or mounted on vehicles.

After World War II, research and development directed toward the improvement of small arms incendiary ammunition were continued. Emphasis was directed toward developing improved ammunition with an increased effectiveness per round against jet planes at higher altitudes. This work proved valuable during the Korean Conflict when small arm incendiaries were used in the air conflict against enemy jet aircraft. Other incendiary weapons, including incendiary bombs and flame throwers, also were used widely and effectively in this conflict by the United Nations forces.

The effort applied in the development of incendiary weapons has resulted in peace-time uses for these weapons. Pyrogel (or goop), which contains finely divided magnesium, and which was used in the IM petroleum incendiary mixture, has been found to aid in the burning out of forest cuttings. The flame thrower is of value in fighting forest fires and in destroying unwanted vegetation. Studies into the causes of death by flame carried out during World War II have directed attention of civilian firemen to unsuspected hazards in fighting fires of various kinds. Also, research on the effectiveness of incendiary ammunition against aircraft has been of value in connection with aircraft fires.

Starters, igniters and first fires, as adjuncts to other pyrotechnic devices, have had a history closely associated with such devices. Information describing the development of early Chinese firecrackers includes descriptions of fuses containing potassium nitrate (saltpeter), charcoal and sulfur. In the 18th century mixtures of potassium nitrate, sulfur, charcoal, and iron filings were widely used for pyrotechnic purposes. They were readily ignited and for this purpose a type of quickmatch was employed.

The quickmatch was made from cotton thread or string, moistened with vinegar or brandy and coated with a mixture consisting of 16 parts potassium nitrate, 3 parts charcoal and 1 part sulfur. The mixture was worked into the thread by hand, after which it was dried and cut into suitable lengths. It was then connected to the pyrotechnic device and used as its igniter.

At the beginning of the 19th century phosphorus-tipped sticks, that could be readily ignited by friction, were made available and were the forerunner of present day matches.

Friction starters were developed later in the 19th century. These employed as a bead a mixture of potassium chlorate and sugar with gum arabic as a binder. In the form of matches, these were ignited by drawing them through a folded piece of sandpaper.

Typical pyrotechnic munitions in the 19th century consisted of rockets, flares, and fireballs which could be ignited by a mixture of potassium nitrate, sulfur, and arsenic sulfide, which, in turn, was ignited by a quickmatch.

During World War I, pyrotechnic munitions were developed which used compositions more difficult to ignite than earlier compositions. In the period between World War I and World War II, limited effort was made to produce more satisfactory ignition mixtures for pyrotechnic munitions. A considerable part of this effort was directed toward the development of satisfactory starter mixtures for HC smoke mixtures and for thermite-type incendiaries. During World War II, emphasis was again directed, mainly, toward developing compositions which would meet the immediate needs of the troops. A relatively small amount of effort has been expended since World

War II, particularly in connection with the development of new illuminants.

In addition to their value as a source of heat, the utility of combustion processes as a means for measuring and controlling time intervals was recognized early in history. The ancient Chinese, Greeks, and others used open vessels of oil, crude candles, and similar devices, to ignite either explosives or flammable material at a distance or at some delayed time. In addition to their military applications, such delayed reactions—culminating in the sudden production of fire, smoke, or a minor explosive phenomenon—were an important part of many early religious ceremonies.

The introduction of gunpowder stimulated the development of somewhat more sophisticated delay devices. A string or paper impregnated with an oxidizer and elongated trails of powder were some of the earliest pyrotechnic delay trains. Present quickmatch and firecracker fuses are of this type, however, they are normally used as transfer media rather than timers. Fuses consisting of an ingredient such as black powder, contained in a tubular cover, will burn reliably and at reasonably reproducible burning rates. Safety fuse is of this type. It is a lightly wrapped train of potassium nitrate and black powder burning at a rate of 40 to 120 seconds per yard. The tubular cover now is often impregnated fabric. An effort is usually made to seal against moisture by the use of wax and plastic coatings. The development of these fuses made possible lavish firework displays by crudely timing the sequence of events starting with the propagation of the display into the air followed by a sequence of bursts making up the firework display. In addition, their use provided the necessary time required for safety of the personnel igniting extensive ground displays. Fuses of essentially the same type were also used in connection with the early commercial explosives used in mining and construction.

The use of projectiles containing explosives was started sometime after the introduction of artillery in military operations. Early projectiles were filled with gunpowder and closed with a wooden plug containing a small diameter hole, also filled with powder. This crude fuse was ignited by the propelling charge and burned slowly until the projectile arrived at or close to the target. Similar crude delay trains were developed for incendiary and other projectiles used in early naval warfare when ships were made of wood. Their purpose was not only to delay functioning until a projectile reached its target, but also to further delay functioning so as to maximize its effectiveness in damaging the enemy ship.

With the development of improved ammunition, more complicated fuse systems with improved reliability and timing accuracy were required. The earliest pyrotechnic delays which were relatively accurate consisted of carefully produced black powder trains or black powder rings. The delay train was used in fuses requiring a set delay while the ring delay was most often used in those items requiring setting immediately before use. In spite of the many problems associated with the use of black powder delay compositions, due mainly to their hygroscopic and corrosive nature, they served as the basis of most pyrotechnic delay trains throughout World War II.

Burning black powder liberates large amounts of gaseous products which, in most fuse designs, are vented to the atmosphere. In the development of ammunition, especially antiaircraft ammunition during World War I, it was found that the burning rate of black powder was affected considerably by the rotational speeds of the projectile as well as the varying ambient pressures. Therefore, the development of a more satisfactory fuse powder composition was started with a low priority after World War I.

The first nongaseous delay powder—consisting of red lead, silicon, and glycerin (84/15/1)—was developed in 1931. Since this composition burned too fast, slower burning powders containing lead chromate, silicon, and linseed oil (89/10/1) were developed. Lack of personnel and funds, however, prevented a comprehensive, systematic study of the many possible inorganic exothermic reactions before the start of World War II. As a result, black powder was again widely used in delay elements during World War II.

In 1942, a comprehensive study of possible gasless delay mixtures was started.[22] While this study was in progress, an urgent need developed for delay powders to be used in the bombs used

in "skip bombing." A composition—containing manganese, barium chromate, and sulfur—which had been prepared on a laboratory scale, proved satisfactory in spite of the many difficulties encountered in proceeding from a laboratory to a production scale.[23] The Navy developed, under contract, a delay mixture containing nickel, zirconium, potassium perchlorate, and barium chromate which was used satisfactorily in hand grenades. While these delay powders—developed under wartime conditions—were used operationally, they were far from optimum.[24]

Work after the end of World War II was directed toward the development of more satisfactory gasless delay compositions. The availability of certain powdered metal fuels—e.g., zirconium-nickel alloys and boron—not available earlier, helped in the development of the presently used more satisfactory delay powders.

The development and use of thermal batteries[25,26] required a controlable heat source to melt the electrolyte which is solid at normal temperatures and to activate the battery. Early thermal batteries were activated by weighed quantities of loose heat powder, similar to delay compositions, introduced directly into the battery cases. Slightly improved results were obtained when the battery was divided into compartments and the loose heat powder added to each compartment. Better results were obtained when the heat powder was mixed with inorganic fibers and made into heat paper by conventional paper making techniques.[26,27]

5-2 INTRODUCTION

Pyrotechnic mixtures, when burned, release chemical energy in the form of heat. The heat energy released is used for the production of light, smoke, gas, and sound. Although the heat effects produced in the surroundings by these items are usually incidental and may be undesirable, there are a number of pyrotechnic items in which the production of heat is the primary function.

Pyrotechnic heat producing mixtures can be divided into two general categories, namely:

1. Compositions which produce heat at a high rate:

a. Ignition mixtures which can be initiated by mechanical, chemical, electrical, or other stimuli of low energy and produce sufficient heat to cause the ignition of other, less sensitive mixtures.

b. First fires, starters, igniters, and similar less sensitive, but relatively easy-to-ignite mixtures, normally activated by the heat produced by another thermal source. The sensitivity level of these mixtures is such that sufficient quantities can be used to supply the heat necessary for ignition of a third mixture or main charge consisting of a propellant or pyrotechnic composition. A similar sequence of ignitions is also common to explosive items.

c. Incendiary mixtures which are used for destructive ignition of combustible materials.

2. Compositions which produce heat at a low rate:

a. Heat powders which produce a controlled amount of heat for applications such as the activation of heat batteries or a controlled evolution of gas, and for other purposes.

b. Delay mixtures which are used to accurately control the time interval between initiation and final functioning.

The rate and control of the heat output from a pyrotechnic mixture, as well as the heat transfer mechanisms involved, are very important in the performance of its function. In this chapter, these characteristics are emphasized as regards existing heat producing pyrotechnic devices.

5-3 THEORY

The two important means by which energy can be transferred are heat and work. Both of these energy forms are transient in nature since they exist only when there is an exchange of energy between two systems or a system and its surroundings. If this transfer takes place without a transfer of mass, and not as a result of a temperature difference, the energy is said to have been transferred through the performance of work. If the exchange is due to a temperature difference, the energy is said to have been transferred in the form of heat.

The amount of energy transferred as heat from a burning pyrotechnic mixtures depends on: (1) the amount and rate of energy released, (2) the products formed, (3) the temperature reached by

the products, (4) the method by which the energy is transferred, and (5) the characteristics of the material being heated, whether unburned pyrotechnic mixture or other combustible.

5-3.1 AMOUNT OF ENERGY RELEASED[1]

The energy released by the reaction of a pyrotechnic mixture can be calculated by the methods outlined in Chapter 3 (Paragraph 3-2.2.1) of this handbook or can be determined experimentally by bomb calorimetric measurements.

Certain generalizations can be made from the results of these calculations involving metals and oxidizers which might be considered for heat producing mixtures. For a given fuel, the heat evolved per unit-volume of the mixture (calculated from the theoretical density for the mixture) depends on the oxidixer used, as is indicated in Table 5-1 which is a summary of the heat evolved when aluminum reacts with various oxidizing agents. In general, for a given oxidizer action the heat evolved depends on the oxidizer anion in the following decreasing order:

$$ClO_4 > ClO_3 > NO_3 > MnO_4 > SO_4 > Cr_2O_7 > CrO_4$$

As also shown in Table 5-1 for a given oxidizer anion, copper salts yield more heat than lead compounds and either of these yields more than sodium, potassium, calcium, or barium compounds when reacted with the same fuel. While copper salts appear best, they are not commonly used because of the difficulty involved in their ignition. The reactions are listed in order of the heat evolved in calories per cubic centimeter of mixture; the heat evolved per gram of mixture is also given, for comparison. In each case, the calculated heat of reaction is based on a particular (most common) stoichiometry for the reaction; the indicated values would vary where different stoichiometries are possible. Since the oxidizer exerts the greatest influence on the heat of reaction, the replacement of aluminum with other reducing agents would result in an arrangement similar to that shown in Table 5-1.

The amount of oxygen available from a given amount of oxidizer is the basic criterion upon which oxidizers are judged. Three classes of oxidizers which have been widely used in incendiary compositions are the inorganic nitrates, perchlorates, and peroxides. The total and available oxygen for some of these oxidizers are given in Tables 5-2,[2] 5-3, and 5-4. Many of the potentially good oxidizers listed in these tables contain large quantities of water in their normally occurring crystalline forms. This reduces the available oxygen from a given quantity of oxidizer and can affect burning (as an inert) as well as stability in storage. Approximate decomposition temperatures are also

TABLE 5-1
HEATS EVOLVED FROM REACTIONS OF ALUMINUM AND VARIOUS OXIDIZING AGENTS

Reaction	*Cal/cc*	*Cal/g*
$Al + NaClO_4$	7,000	2,600
$Al + NaClO_3$	6,300	2,500
$Al + KClO_4$	6,100	2,400
$Al + Pb(NO_3)_2$	5,800	1,500
$Al + KClO_3$	5,400	2,200
$Al + PbO_2$	4,900	700
$Al + CuSO_4$	4,700	1,400
$Al + CuO$	4,600	900
$Al + NaNO_3$	4,400	1,800
$Al + Ba(NO_3)_2$	4,200	1,400
$Al + PbSO_4$	4,200	800
$Al + KNO_3$	4,000	1,800
$Al + CaSO_4$	3,800	1,300
$Al + KMnO_4$	3,600	1,300
$Al + Fe_2O_3$	3,500	900
$Al + MnO_2$	3,400	1,100
$Al + BaSO_4$	3,400	900
$Al + Fe_3O_4$	3,400	800
$Al + Na_2SO_4$	3,300	1,200
$Al + Pb_3O_4$	3,300	400
$Al + Na_2O_2$	3,100	1,600
$Al + K_2SO_4$	3,100	1,200
$Al + NH_4NO_3$	3,000	1,600
$Al + Na_2CrO_4$	2,800	1,000
$Al + K_2Cr_2O_7$	2,800	1,000
$Al + BaO_2$	2,600	600
$Al + PbO$	2,500	300
$Al + BaCrO_4$	2,400	600
$Al + K_2CrO_4$	2,200	800

TABLE 5-2
OXYGEN CONTENT OF VARIOUS NITRATES

Nitrate	Density g/cc	Approx. Decomp. Temp, °C	Oxygen Contained g/g	Oxygen Contained g/cc	Oxygen Available g/g	Oxygen Available g/cc
Liquid O_2	1.14	—	1.00	1.14	1.00	1.14
Liquid O_3	1.71	—	1.00	1.71	1.00	1.71
Aluminum $(+H_2O)$[1]	—	130	.77	—	.32	—
Ammonium	1.73	210	.60	1.04	.20	.35
Barium	3.24	600	.37	1.19	.31	.99
Beryllium $(+H_2O)$[1]	—	100	.78	—	.39	—
Calcium $(+H_2O)$[1]	2.36	560	.59	1.38	.48	1.14
Chromium $(+H_2O)$[1]	—	100	.71	—	.32	—
Cobalt $(+H_2O)$[1]	—	100	.59	—	.44	—
Copper $(+H_2O)$[1]	—	150	.51	—	.42	—
Iron (Ferric) $(+H_2O)$[1]	—	100	.47	—	.39	—
Lead	4.53	470	.29	1.31	.24	1.10
Lithium $(+H_2O)$[1]	2.38	260	.69	1.65	.58	1.38
Magnesium $(+H_2O)$[1]	—	100	.75	—	.62	—
Manganese	—	130	.54	—	.40	—
Potassium	2.11	400	.47	1.00	.40	.84
Sodium	2.26	350	.56	1.28	.47	1.06
Strontium	2.99	600	.45	1.38	.38	1.13

[1] (H_2O) indicates that a hydrate of the nitrate is a common form of the salt. All data presented in the table, however, are for the anhydrous salt.

given in these tables. The thermal decomposition of many of the possible oxidizers has been studied in detail.[8]

In Table 5-5, reactions are shown between various metallic and nonmetallic reducing agents, and barium peroxide. The heats evolved from reactions of these materials with other oxidizing agents would generally rank in the same order.

Some of the combinations included in Table 5-5, such as barium peroxide with tin, chromium, and zinc, are so insensitive that the peroxide would decompose before ignition occurred. Conversely, red phosphorus and sulfur with peroxides can be sensitive to the point of spontaneous decomposition and constitute a hazard. The equivalent heat value given in this table is the heat evolved for the reactions, as given in the equations, divided by the number of equivalent weights of reducing agent in the equation. The equivalent heat has been used as a measure of the reducing power of these compounds.

It should be noted that combustion of liquid hydrocarbon fuels such as gasoline and kerosene, which were widely used as incendiaries during both World War II and the Korean Conflict, results in the evolution of about 10 kilocalories per gram. This is considerably better on a weight basis than for the metal incendiary materials: thermite, 0.8 kilocalories per gram, and magnesium, 0.6 kilocalories per gram. However, the temperature reached by the hydrocarbon-oxygen reaction is less than that reached by incendiaries incorporating metal fuels.

5-3.2 HEAT TRANSFER

The efficiency and performance of pyrotechnic devices are considerably influenced by the various modes and rates of heat transfer present through-

TABLE 5-3
OXYGEN CONTENT OF VARIOUS PERCHLORATES

Perchlorate	Density g/cc	Approx. Decomp. Temp, °C	Oxygen Contained g/g	Oxygen Contained g/cc	Oxygen Available g/g	Oxygen Available g/cc
Liquid O_2	1.14	—	1.00	1.14	1.00	1.14
Liquid O_3	1.71	—	1.00	1.71	1.00	1.71
Ammonium	1.95	—	0.54	1.06	0.27	0.53
Barium (H_2O)[1]	—	500	.38	—	.33	—
Cobalt (H_2O)[1]	3.33	—	.50	1.65	.40	1.34
Copper	—	110	.27	—	.16	—
Iron (H_2O)[1]	—	—	.62	—	.29	—
Lead (H_2O)[1]	2.6	100	.31	.99	.24	.63
Lithium (H_2O)[1]	2.43	410	.60	1.47	.53	1.28
Magnesium (H_2O)[1]	2.60	—	.57	1.48	.50	1.30
Potassium	2.52	400	.46	1.16	.40	1.02
Sodium (H_2O)[1]	2.49	480	.52	1.29	.46	1.15

[1] (H_2O) indicates that a hydrate of the perchlorate is a common form of the salt. All data presented in the table, however, are for the anhydrous salt.

TABLE 5-4
OXYGEN CONTENT OF VARIOUS OXIDES AND PEROXIDES

Oxide or Peroxide	Density, g/cc	Approx. Decomp. Temp, °C	Oxygen Contained g/g	Oxygen Contained g/cc	Oxygen Available g/g	Oxygen Available g/cc
Liquid O_2	1.14	—	1.00	1.14	1.00	1.14
Liquid O_3	1.71	—	1.00	1.71	1.00	1.71
Barium Peroxide (H_2O)[1]	4.96	—	.19	.94	.09	.47
Calcium Peroxide (H_2O)[1]	—	280	.44	—	.22	—
Chromium Trioxide (H_2O)[1]	2.7	190	.48	1.30	.24	.65
Iodine Pentoxide	4.80	300	.24	1.15	.24	1.15
Iron (Fe_2O_3)	5.12	—	.30	1.54	—	—
Lead Dioxide	9.38	290	.13	1.26	.07	.63
Manganese Trioxide	—	—	.47	—	.23	—
Potassium Peroxide	2.74	—	.29	.61	.14	.30
Sodium Peroxide (H_2O)[1]	2.81	—	.41	1.15	.20	.58
Strontium Peroxide (H_2O)[1]	—	—	.27	—	.14	—

[1] (H_2O) indicates that a hydrate of the peroxide is a common form of this material. All data presented in this table, however, are for the anhydrous form of these peroxides.

TABLE 5-5
HEAT OF REACTION OF REDUCING AGENTS WITH BARIUM PEROXIDE

Equation	*Heat of Reaction (Kg-cal)*	*Equivalent Heat (Kg-cal)*
$BaO_2 + Mg \rightarrow BaO + MgO$	126.7	63.4
$2BaO_2 + Zr \rightarrow 2BaO + ZrO_2$	219.3	54.8
$3BaO_2 + 2Al \rightarrow 3BaO + Al_2O_3$	321.8	53.6
$5BaO_2 + 2\text{red } P \rightarrow 2BaO + Ba_3(PO_4)_2$	487.6	48.8
$2BaO_2 + Ti \rightarrow 2BaO + TiO_2$	186.2	46.6
$2BaO_2 + Si \rightarrow 2BaO + SiO_2$	162.6	40.7
$BaO_2 + Mn \rightarrow BaO + MnO$	77.1	38.6
$3BaO_2 + 2Cr \rightarrow 3BaO + Cr_2O_3$	214.8	35.8
$BaO_2 + Zn \rightarrow BaO + ZnO$	64.1	32.1
$2BaO_2 + Sn \rightarrow 2BaO + SnO_2$	99.3	24.8
$5BaO_2 + CaSi_2 \rightarrow 5BaO + CaO + 2SiO_2$	236.7	23.7
$3BaO_2 + 2Fe \rightarrow 3BaO + Fe_2O_3$	140.3	23.4
$BaO_2 + Cd \rightarrow BaO + CdO$	45.8	22.9
$3BaO_2 + W \rightarrow 3BaO + WO_3$	137.5	22.9
$3BaO_2 + Mo \rightarrow 3BaO + MoO_3$	118.3	19.7
$2BaO_2 + 2S \rightarrow BaS + BaSO_4$	155.8	19.5
$BaO_2 + Ni \rightarrow BaO + NiO$	39.0	19.5
$BaO_2 + Co \rightarrow BaO + CoO$	38.1	19.1
$3BaO_2 + 2Sb \rightarrow 3BaO + Sb_2O_3$	107.8	18.0
$3BaO_2 + 2Bi \rightarrow 3BaO + Bi_2O_3$	78.9	13.2
$BaO_2 + Cu \rightarrow BaO + CuO$	16.4	8.2
$2BaO_2 + 2Se \rightarrow BaSe + BaSeO_4$	54.3	6.8

out the system. Although extremely complicated mechanisms exist in some cases, a knowledge of the problems involved is important to the improvement of pyrotechnic compositions and hardware design.

Heat is transferred by one or by a combination of the three basic mechanisms: conduction, convection, and radiation. During propagative burning, only one of these modes is controlling.

5-3.2.1 Conduction

In conduction, the heat energy is transferred by molecular motion and free electrons. Materials like the metals, which are good conductors of heat, have a well-ordered crystalline structure and are rich in free electrons. All materials conduct heat to some extent. In liquids and gases, the amount transferred by this method is usually small when compared with the amount transferred by other means. The rate of heat transfer q, at which heat flows across an area A, is given by:

$$q = -kA \frac{dt}{dx} \qquad (5\text{-}1)$$

where k is the thermal conductivity, and dt/dx is the temperature gradient at the point of interest. The rate expressions for a general three-dimensional case are more complex.

The thermal conductivity of the pyrotechnic mixture has been shown to influence the burning rate due to a preheating of the unburned composition (Paragraph 6-3.5). The amount of preheating is usually a function of the metal content of the mixture due to its higher thermal conductivity.

The degree of consolidation also affects the rate of heat transfer. The heat conduction along solid flares has been measured[3] by imbedding thermocouples in the composition at the time of compaction. From these data it was possible to construct a model for relating the instantaneous temperature at a point in the flare to that of the reaction zone.

Conduction heat transfer as well as radiation influence the on-target combustion efficiency of certain types of incendiary mixtures. The rate of energy release of the fuel-oxidant reaction, intimacy of contact, and chemical-physical properties of the target influence the heat transfer rate.

Heat is transferred by conduction as well as by the other modes in ignition trains, delays and heat powders, and should be taken into consideration in establishing design criteria.

5-3.2.2 Convection and Radiation

Convective and radiative modes of heat transfer in pyrotechnics are more closely associated with post-combustion phenomena. Convective heat transfer effects are less important and will only be mentioned briefly. Transfer of heat energy by convection results from the gross movement of the fluid transfer medium. The amount q of heat transferred by convection can be expressed by the general equation:

$$q = hA(\Delta T) \tag{5-2}$$

where h is the heat transfer coefficient, which may be a complex function of a large number of properties including those relating to the fluid motion; A is the cross-sectional area; and ΔT is the temperature difference. Convective heat transfer effects may exert an influence on the luminous output and efficiency of flame plumes by moving oxygen into the combustion area and/or by cooling. These effects are usually slight and their measurement extremely complicated.

Heat transfer by radiation does not require a transfer medium. The amount of energy emitted from a heated surface which has blackbody characteristics is:

$$q = \sigma A T^4 \tag{5-3}$$

where σ is the Stefan-Boltzmann constant, A is the area of the emitting surface, and T the absolute temperature. A graybody, or nonselective radiator, is one in which its emissivity is independent of the wavelength. At a given temperature, the amount of energy emitted per unit area at any wavelength is less than that from a blackbody. The net heat exchange between two bodies in which both the hot and cold body are graybodies is:

$$q_{net} = q_h - q_c \tag{5-4}$$

where the net heat exchange is the difference between the amount of heat q transferred by radiation to the cooler body, less the amount q transferred from the cooler to the hotter body. This may be written also as:

$$q_{net} = E_h \alpha_c F_{h \rightarrow c} A_h \sigma T_h^4 - E_c \alpha_h F_{c \rightarrow h} A_c \sigma T_c^4 \tag{5-5}$$

or by application of the reciprocity theorem:

$$q_{net} = E_h \alpha_c F_{h \rightarrow c} A_h \sigma (T_h^4 - T_c^4) - E_c \alpha_h F_{c \rightarrow h} A_c \sigma (T_h^4 - T_c^4) \tag{5-6}$$

where E is the emissivity, α is the absorptivity, F is the fraction of the energy emitted by a radiating body that is absorbed by the absorbing body, A is the area of the emitting surface, σ is the Stefan-Boltzmann constant, and T is the absolute temperature. The subscripts h refer to the hotter body, and the subscripts c refer to the cooler body.

Radiation heat transfer is important in post-combustion phenomena of pyrotechnic flares since it is the primary mechanism by which heat is returned to the reaction zone. This feedback is important to the maintaining of propagative burning and maximum possible efficiencies in these type reactions. As already indicated, radiative heat transfer mechanisms also influence the efficiency of certain types incendiary mixtures. In this case, it is expedient to produce radiating species which will be readily absorbed by the target.

5-3.3 HEAT EFFECTS

If heat is transferred to or from a system, the temperature of the system usually changes. The magnitude of the temperature change depends on the mass of a system and its heat capacity. These quantities are discussed in Paragraph 3-2.1. Transfer of heat may also cause phase changes such as crystalline transition, melting (or freezing), vap-

orization (or sublimation), and dissociation. The energy involved in these changes in state may be large in comparison with those involved in the raising or lowering of the temperature of the system. Changes in state brought about by the absorption of heat may be extremely important in initiating combustion since the fuel and oxidizer must in some cases be converted into the gaseous state for the combustion process to proceed.

5-4 INCENDIARIES

Incendiary devices are used to initiate destructive fires in a large variety of targets. While aircraft, buildings, industrial installations, ammunition, and fuel dumps are among the principal targets for incendiary attack, incendiaries have proved to be effective against personnel, armored vehicles, and tanks. In many cases, the psychological fear of fire increases the effectiveness of an incendiary attack as personnel may abandon relatively safe positions and vehicles thus exposing themselves to the action of other weapons.

Incendiary compositions and incendiary devices can be classified in many ways depending on their composition and use. In this handbook, incendiaries are grouped into three large classes based on their use:

1. Small arms incendiary ammunition used primarily against aircraft and fuel dumps.
2. Other incendiary munitions including bombs, grenades, mortar and artillery projectiles, to initiate fires in buildings, industrial installations, ammunition, fuel dumps and other targets in the combat zone, in areas behind the combat area, and in the zone of interior of the enemy.
3. Special incendiary devices used for covert purposes, in connection with guerrilla operations, and for the destruction of material and documents.

5-4.1 SMALL ARMS INCENDIARY AMMUNITION[6]

Small arms incendiaries are used primarily for starting destructive fires in aircraft fuels. The burst produced serves, basically, as an ignition source for the fuel carried by the aircraft since it is unlikely that a small arms incendiary burst of sufficient intensity or duration would weaken aircraft structures. It is important that the bullet or projectile provide a hole in a self-sealing fuel tank so that some fuel is spilled and ignited by the burning incendiary material. This emphasizes the importance of widespread distribution of burning particles and long burst duration. Most small arms incendiary compositions are mixtures of metal, or metal alloys, and an oxidizing compound. These mixtures when initiated, in contrast to some other incendiaries, usually burn rapidly; often with explosive violence. Unfuzed incendiary rounds up to 20 mm sizes are usually initiated by the heat produced from the crushing of the metal nose by impact while 20 mm and larger sizes are provided with fuzes which are initiated by impact.

The functioning of a thin metal nose, nonfuzed, small arms incendiary bullet can be divided into three separate stages:

1. Initiation of incendiary compositions by bullet impact on target.
2. Rapid burning and heating of the composition and its combustion products until a maximum temperature is reached and the burning contents burst from the bullet jacket.
3. Cooling of the products from their maximum temperature to the minimum effective temperature, i.e., the minimum temperature necessary for fuel ignition.

The chain of reaction with fuzed incendiary rounds, such as 20 mm, is similar to that described except that the sensitive fuze starts ignition upon impact.

The degree of penetration before initiation of the burst is determined, primarily, by the sensitivity of the bullet and its ability to carry through target areas to the interior of the aircraft. The physical size of the incendiary burst produced also affects its burst location in the aircraft. This has been found to be especially important in the case of sparking-type incendiary compositions since they spread throughout a target area and produce a very large and effective burst volume.

For many incendiary compositions, for which the burning time is very short, the effective burst duration is the time required for the products to cool to the minimum temperature required for fuel ignition. In other mixtures which contain relatively

TABLE 5-6
SUMMARY OF LIMITS OF FLAMMABILITY OF VARIOUS GASES AND VAPORS IN AIR AND IN OXYGEN

Gas or Vapor	*Limits in Air, %*				*Limits in Oxygen, %*				*Oxygen Percentage Below Which No Mixture is Flammable*	
	Lower		*Higher*		*Lower*		*Higher*		*Nitrogen as Diluent of Air*	*Carbon dioxide as Diluent of Air*
HYDROCARBONS										
Methane	5.3	(5.0)	14	15	5.1		61		12.1	14.6
Ethane	3.0		12.5	15	3.0		66		11.0	13.4
Propane	2.2		9.5		2.3		55		11.1	14.3
Butane	1.9		8.5		1.8		49		12.1	14.5
Isobutane	1.8		8.4		1.8		48		12.0	14.8
Pentane	1.5	1.4	7.8						12.1	14.4
Isopentane	1.4		7.6							
2-2 Dimethyl propane	1.4		7.5							
Hexane	1.2		7.5						11.0	14.5
Dimethyl butane	1.2		7.0							
2-Methyl pentane	1.2		7.0							
Heptane	1.2	1.1	6.7							
2-3 Dimethyl pentane	1.1		6.7							
Octane	1.0									
Iso-octane	1.1	1.0		6.0						
Nonane		.8								
Tetramethyl pentane	.8		4.9							
Diethyl pentane		.7		5.7						
Decane	.8			5.4						
Ethylene	3.1	2.7	32	34	3.0		80		10.0	14.7
Propylene	2.4	2.0	10.3	11	2.1		53		11.5	14.1
Butylene	2.0		9.6							
Butene-1	1.6		9.3		1.8		58		11.6	14.0
Butene-2	1.8		9.7		1.7		55			
Isobutylene	1.8		8.8							
b-n-Amylene	1.5	1.4	8.7							
Butadiene	2.0		11.5						10.4	13.1
Acetylene	2.5	(2.3)		81						
Benzene	1.4		7.1						11.2	13.9
Toluene	1.4	1.3		6.7						
o-Xylene		1.0		6.0						
Ethyl benzene	1.0									
Styrene		1.1		6.1						
Butyl benzene		.8		5.8						
Naphthalene		.9		5.9						
Cyclopropane	2.4		10.4		2.5		60		11.7	13.0
Ethyl cyclobutane	1.2		7.7							
Ethyl cyclopentane	1.1		6.7							
Cyclohexane	1.3		8							
Methyl cyclohexane	1.2									
Ethyl cyclohexane	.9		6.6							
MIXTURES										
Water gas	7.0		72							
Carbureted water gas	5.5		36							
Pittsburgh natural gas	4.8		13.5						12.0	14.4
Other natural gases	3.8–6.5		13–17							
Benzine	1.1									
Gasoline	1.4		7.6						11.6	14.4
Naphtha		0.8		5						
Kerosene		.7		5						
Coal gas	5.3		32			7		70	11.5	14.4
Coke-oven gas	4.4		34							
Blast furnace gas	35		74							
Producer gas	17	20–35	70	70–80						
Oil gas	4.7		33							

slow-burning metal fuels, the burning time is an appreciable part of the total burst duration.

5-4.1.1 Ignition and Combustion of Aircraft Fuels

It is generally accepted[9,10] that the combustion of a hydrocarbon: (1) occurs in the gas phase, (2) involves a chain-reaction mechanism which includes the formation of unstable species such as free atoms and free radicals, and (3) can occur only when the concentration of the hydrocarbon vapor in the air falls within certain well-defined limits, as illustrated in Table 5-6.[11] Normal variations in atmospheric pressure do not appreciably affect the limits of flammability; and, for most mixtures, there is a straight line relationship between the limit of flammability and the initial temperature of the mixture.[12]

For fuel concentrations within the flammability zones, a fire or explosion can result from contact with an incendiary source when the temperature of this source is sufficiently high. Various methods have been tried to determine the minimum ignition temperatures for various liquid fuels. A popular experimental procedure for such determinations involves confinement of the fuel vapor and air mixture in a suitable container and application of external heat until the mixture ignites. In general, the hydrocarbons of a higher molecular weight tend to ignite at lower temperatures. There exists, however, an ignition lag[13] (Paragraph 3-3.6.1) which is dependent upon several variables.

Grades JP-1 and JP-3 aviation fuel have minimum ignition temperatures between 400°F and 500°F, with an associated ignition lag from 100 to 200 seconds. Aviation gasolines have minimum ignition temperatures of 800°F to 950°F with an ignition lag of 2.0 to 2.5 seconds.[14] The ignition lag for all hydrocarbon fuels becomes less with increasing temperatures. At the minimum ignition temperature of gasoline, about 900°F, the ignition lag for kerosene is in the range of 2 to 10 seconds.[15] Fires, therefore, can be initiated and propagated in a flammable kerosene vapor and air mixture as readily as in a gasoline vapor and air mixture if both mixtures are within the flammability zone. Consequently, factors which control the formation of fuel vapor are of primary importance in determining ignition characteristics.

The energy required to vaporize a given quantity of kerosene is somewhat less than that for gasoline. The energy must be available, however, at somewhat higher temperatures because of the lower volatility of kerosene. The energy made available for evaporation of fuel by the flame of a self-propagating fire is roughly the same for gasoline and kerosene inasmuch as heat of combustion for both fuels lies in the range of 20,000 to 22,000 BTU per pound.

It is well established[16] that fires can be initiated by an incendiary bullet penetrating self-sealing aviation fuel cells above the liquid level, if the free space contains air, perhaps because of a previous puncture or air leaking into the tank. Rarely, if ever, has a fire been started inside the tank by an incendiary bullet striking below the liquid level. In fact, during developmental tests of incendiary ammunition, care was always taken to strike the tank below the liquid level with a second shot if the first shot failed to ignite. All effort was toward developing an incendiary bullet with one shot ignition capability below liquid level as this was most difficult to achieve. Success was achieved when incendiaries of long burst duration and long particle burning time were developed. These long burning particles ignite the small spurt of fuel which is forced through the bullet hole after 30 to 50 milliseconds by the pressure wave set up inside the tank by the bullet.

Flame will propagate in kerosene mist-air mixtures for a wider range of concentrations than in kerosene vapor-air mixtures. It is impossible to obtain a concentration of kerosene mist in air too rich to be ignited if the temperature is below the flash point of kerosene. However, at temperatures high enough to produce a vapor concentration in air near the upper limit of flammability, the mixture may be so rich that it fails to propagate. The initiation of a mist explosion takes place after the evaporation of mist droplets near the ignition source from a local vapor concentration within the explosive limits. This vapor ignites to form the initial flame front. Propagation of the flame proceeds by evaporation of droplets which form an inflammable gas mixture in the preheating zone in advance of the flame front.

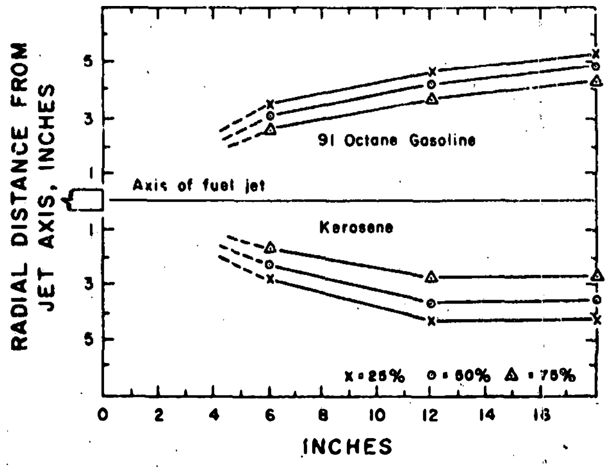


Figure 5-1. Constant Ignition Probability Regions About a Fuel Jet of Gasoline or Kerosene

Studies of phenomena associated with the penetration of liquid fuel tanks show that hydrodynamic forces resulting from the impact of a projectile on an aircraft fuel cell produce a pressure wave in the stored liquid. A high, positive pressure is near the point of tank penetration a few milliseconds after impact by the projectile. The fuel spray emerging from the hole made by the projectile has the normal characteristics of filament jets with droplets forming at the leading edge of the filament.

The basic factors which account for the differences in flammability characteristics of aircraft fuels are the relative volatility and viscosity of the fuels. The relatively low volatility and high viscosity of kerosene make it considerably more difficult to ignite than gasoline. Results of tests (with fuel jets designed to simulate the fuel spray made as a projectile penetrates a fuel tank) presented in Figure 5-1 indicate that the probability of a positive ignition is greater for gasoline than for kerosene at any point in the volume surrounding the axis of the jet. The type of fire occurring with the gasoline jet is usually different than that occurring with kerosene. Most gasoline fires propagate rapidly through the fuel spray. Little, if any, unburned fuel is left in the area. In contrast, nearly all kerosene ignitions are localized, seldom propagating more than a few inches from the point of ignition so that most of the fuel is left unburned.

The effectiveness of incendiary ammunition also depends strongly on the ambient pressure and the supply of oxygen from the atmosphere since these factors are important if a self-sustaining fire is to result from the action of incendiary bullets. Information obtained from tests in partially inert atmospheres, both in altitude chambers and in actual flight tests, indicates that damaging fuel fires cannot be started at very high altitude. Studies with several pure fuels indicate that the relationship between spark minimum ignition energy H and pressure for a fuel-air mixture can be represented by:[18]

$$H = \frac{k}{p^n} \tag{5-7}$$

where p is the pressure, k is a constant which depends on the nature of the fuel, and n is another constant having a value of about 1.82. Even if fires are initiated at high altitude, the nature of the fires, especially at the higher airflows, might be diffused and low in temperature, thus limiting the damage produced.

5-4.1.2 Nature of a Small Arms Incendiary Burst

As already indicated, the burst produced by the functioning of small arms incendiaries is fundamentally an ignition source for starting a destructive fuel fire in an aircraft. The amount of energy transferred to the fuel depends on the nature of the combustion process (the temperature reached and the characteristics of the products of combustion), the mode of energy transfer process, and the efficiency with which the energy is absorbed by the fuel.

The maximum temperature reached in an incendiary burst is a measure of both its relative intensity and duration, as a result of chemical reactions which occur within the burst to the end of its cooling cycle. A consideration of the burst temperature, and the effects of the physical and thermodynamic properties of incendiary mixture ingredients and their reaction products, comprise an important area of study concerning an incendiary burst. The temperature produced by an incendiary burst can be estimated by calculations using the methods outlined in Paragraph 3-2.5. It is necessary to assume, arbitrarily, the amount of atmospheric oxygen available for combustion of the

incendiary mixture. The extreme conditions are either: (1) that the only oxygen available for combustion is that contained in the mixture components due to insufficient time for the diffusion of atmospheric oxygen into the flame; or (2) that the surrounding air supplies the additional oxygen required for complete combustion of the reactants. The actual condition is probably somewhere between. Limited experimental data obtained for bursts in controlled atmospheres indicate that the surrounding atmosphere does not enter appreciably into the incendiary reaction so that condition (1) is the better assumption. The difference in the results is small, however, because of the necessity for heating the nitrogen of the air under assumption (2). (See also Example 4, Paragraph 3-2.5.)

The rate of heat transfer from the burst cloud to its surroundings depends also upon the method by which the heat is transferred. Heat can be transferred by combustion, convection, and radiation; however, at temperatures above the ignition temperature of aircraft fuels, heat transfer by radiation is probably the dominant method. Radiant energy emitted by the liquid, solid, and gaseous species in an incendiary burst is a complicated function of wavelength, pressure, geometry, and chemical composition of the emitting molecular aggregate, as well as of temperature. However, based on experimental results, it can be assumed that the incendiary burst cloud radiates as a graybody with a relatively high emissivity.

The rate of heat transfer from an incendiary burst cloud, radiating as a graybody may be expressed by:

$$dQ/d\theta = \frac{E_B E_S \sigma (T_B^4 - T_S^4) A}{E_B + E_S - E_B E_S} \qquad (5\text{-}8)$$

where A is the total radiating area of the components in the burst cloud, dQ is quantity of heat radiated by the incendiary burst cloud during time interval $d\theta$, σ is the Stefan-Boltzmann constant, E is the emissivity, and T is the absolute temperature. The subscript B refers to the burst and the subscript S refers to the surroundings. By combining this equation with the equation $dQ = mCdT$ where C is the overall average specific heat—i.e., equals the heat evolved per gram, including that from phase changes, in the cooling of the reaction products from the maximum temperature reached by the incendiary burst to the minimum effective temperature divided by the temperature difference—and neglecting T_S^4 since it is very much smaller than T_B^4, integration yields:

$$\theta^2 = \left(\frac{1}{T_2^3} - \frac{1}{T_1^3}\right)\frac{m}{3}\,\frac{(E_B + E_S - E_S E_B)C}{\sigma E_S E_B A} \qquad (5\text{-}9)$$

If it is assumed that the radiating area A and emissivities E_B and E_S have average values which may be assumed constants for the various bursts, the terms outside of the parentheses may be considered a constant K and:

$$\theta_2 = kC\left(\frac{1}{T_2^3} - \frac{1}{T_1^3}\right) \qquad (5\text{-}10)$$

If k is assumed to be 10^8 ($A \cong 2 \times 10^4 \text{cm}^2$, $E_B = 0.9$, $E_S = 0.1$ and $m = 1$), the curves in Figure 5-2 result where it is assumed that the minimum effective temperature is 800°K.

If the adiabatic flame temperature can be calculated or experimentally obtained and if the heat of reaction is known, Figure 5-3 can be used to estimate an average specific heat. If Figures 5-2 and 5-3 are combined, Figure 5-4 results. As can be seen, the cooling time varies directly with the average specific heat. The curves also indicate that any increase in the burst temperature above 2000°K results in only a small increase in the cooling time. Change in cooling times resulting from transformations is difficult to determine because the details of the cooling mechanism are not known.

Experimental cooling curves for incendiary mixtures are given in Figure 5-5.[19] IM-11, 50 percent barium nitrate and 50 percent magnesium-aluminum alloy, is one of the standard mixtures used in incendiary bullets. IM-23, 50 percent potassium perchlorate and 50 percent magnesium alloy, contains no barium nitrate and its calculated temperature is higher than that for IM-11. IM-63—50 percent calcium peroxide, 45 percent red phosphorus, and 5 percent aluminum hydroxide—does not contain either barium nitrate or alloy, and has a considerably lower theoretical maximum temperature than IM-11. It is to be noted that IM-103, 50 percent red phosphorus and 50 percent magnesium-aluminum alloy, does not contain an oxidizer.

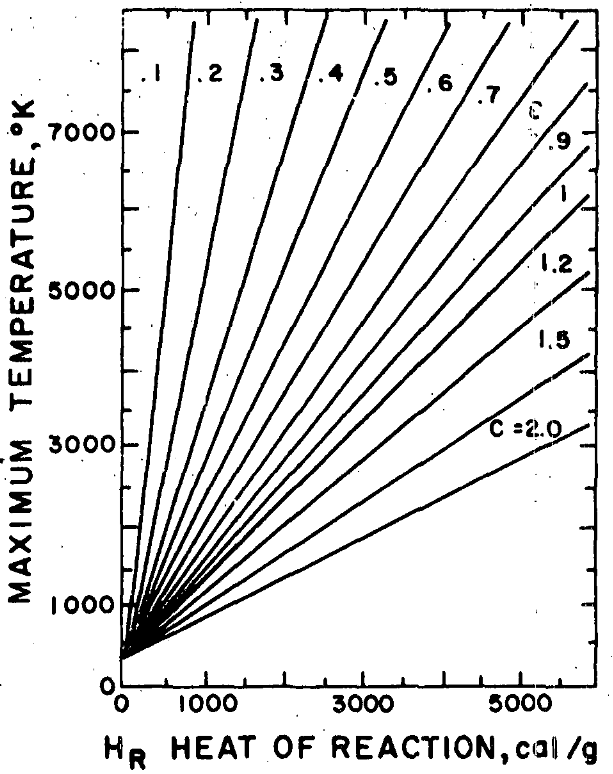


Figure 5-2. Maximum Temperature, T, as a Function of Heat of Reaction and Average Specific Heat, C

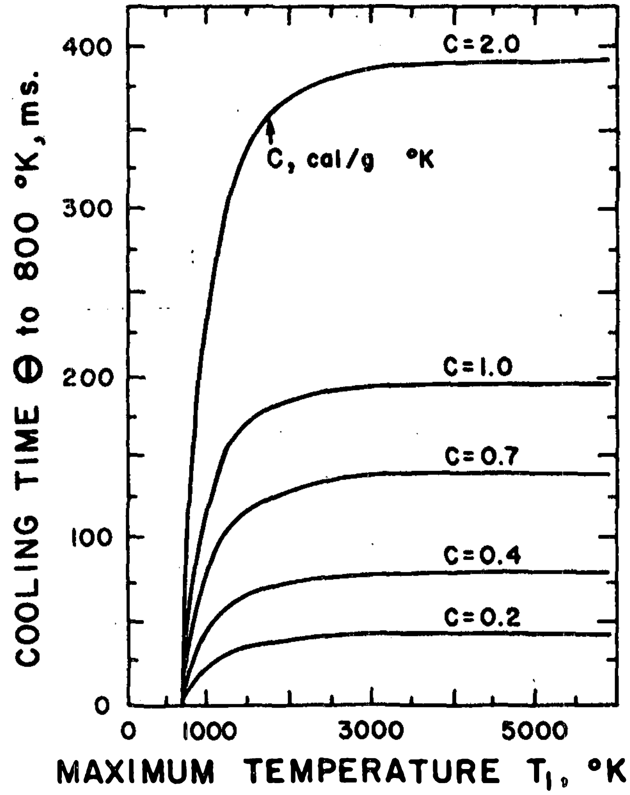


Figure 5-3. Cooling Time to 800°K as a Function of Temperature and Heat Capacity, C

5-4.1.3 Small Arms Incendiary Fillers

Small arms incendiary ammunition, which now includes ammunition through 40 mm, has been developed, like other ammunition, to meet the particular needs of the using Services. Important modifications and improvements were made through the years in response to changes in Service needs or anticipated changes in Service requirements. Early developments in small arms incendiary ammunition fillers have been discussed in the historical review of incendiaries (Paragraph 5-1).

Sensitive explosives—including mercury fulminate, lead azide, and PETN—were employed in some early incendiary fillers. Other explosives—including tetryl, MOX, TNT, Haleite, and EDNA—also have been tried in smaller nonfuzed incendiary ammunition but have not proved satisfactory. High explosive incendiary ammunition in 20 mm and larger sizes contains a purely explosive material in addition to its incendiary filler material.

Magnesium-aluminum alloys have been an essential ingredient in most of the successful incendiary mixtures, and have replaced both white phosphorus incendiaries and tracer compositions. Tracers, first used as incendiaries, employed a filler consisting of two parts magnesium and seventeen parts barium peroxide for incendiary purposes. Until the development of the highly satisfactory incendiary filler based on a magnesium-aluminum alloy (50/50) fuel, with barium nitrate as the oxidizer, changes in tracer mixtures used as incendiaries were limited to those which would improve the performance of metal-oxidant compositions. Numerous incendiary mixtures have been tested for use in small arms ammunition in the period since the beginning of World War II. A detailed card file listing of the incendiary mixtures which have been given an IM number (approximately 1000) is maintained at Frankford Arsenal.

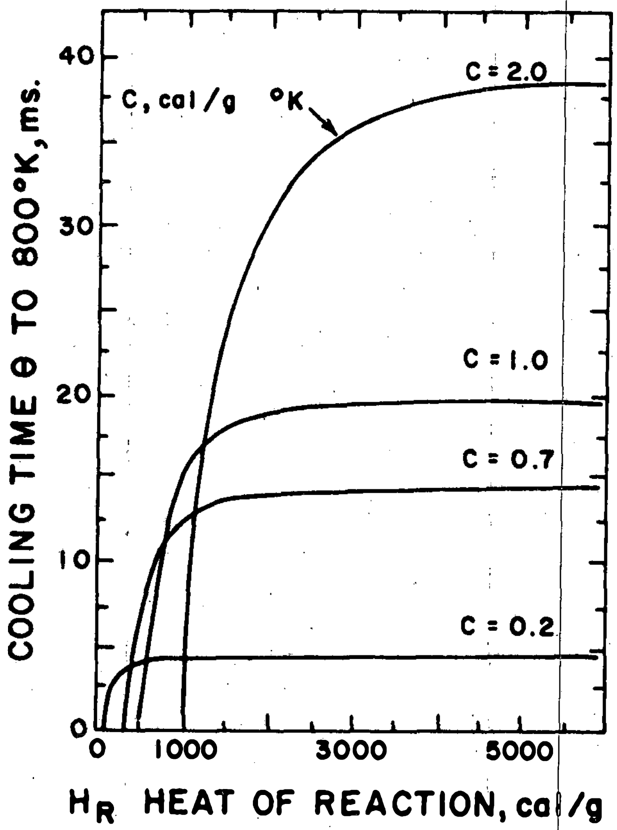


Figure 5-4. Cooling Time to 800°K as a Function of Heat of Reaction and Specific Heat, C

5-4.1.3.1 **Fuels**

Incendiary compositions containing magnesium-aluminum alloy have been the basis of most of the standard incendiary compositions investigated until recent years. Studies have indicated that an alloy of 50/50 proportions, prepared by grinding with a particle size range from 60 to 325 mesh, is optimum for a wide variety of applications. The effects of variation in the granulation of the magnesium-aluminum alloy were evaluated early in the program, leading to the development of IM-11 (composed of 50 percent magnesium-aluminum alloy 50/50, and 50 percent barium nitrate) which was the basic incendiary mixture used in World War II. Figure 5-6 shows the cooling curves and burst duration (the time from ignition until burst cloud cooled to 1540°K) curves for mixtures which contain either the ground or atomized alloy in a variety of mesh sizes with some barium nitrate. The results presented in this figure indicate that an increase in burst duration and cooling time results with coarser and with atomized or spherical particles. Firing tests confirm these results. Evaluations of magnesium-aluminum alloys other than 50/50 show that the 50/50 alloy is superior for a variety of applications whether ground or atomized.

In an attempt to develop improved small arms incendiary mixtures, a large number of metals and alloys were evaluated for their effectiveness as incendiary fuels with several oxidizing agents, as reported in detail in Reference 6. Some of these mixtures produced incendiary bursts which have a longer duration than those produced by IM-11. These mixtures also have proved to be more effective than IM-11 in comparative tests against aircraft targets.

5-4.1.3.2 **Oxidizers**

A wide variety of materials have been used as oxidizers in incendiary mixtures. An oxidizer, for use in mass-produced items which are loaded by automatic machines, must meet a variety of requirements in addition to being able to supply the necessary quantity of oxygen.

The effects of oxidizer particle size on incendiary bursts have been studied. Incendiary mixtures containing oxidizer particles of comparatively large size (100 to 200 mesh) could not be ignited unless the mixture contained finely divided (less than 325 mesh) alloy fuel particles. Mixtures containing fine or medium-sized barium nitrate particles would not burn except when mixed with coarse alloy. Alloy particle sizes in the range specified for IM-11 reacted erratically with either a narrow range coarse or a fine barium nitrate powder. Specification grade alloy reacted best with barium nitrate which consisted of both fine and coarse particle sizes. The cooling durations of the incendiary burst for the few mixtures which could be ignited increased as the particle size of the barium nitrate was increased, but these changes were relatively small.

Some of the alkali metal and alkaline earth nitrates have been more widely employed than other types of oxidizers because they are available at low cost, contain large quantities of available oxygen, are safe, and can be handled easily.

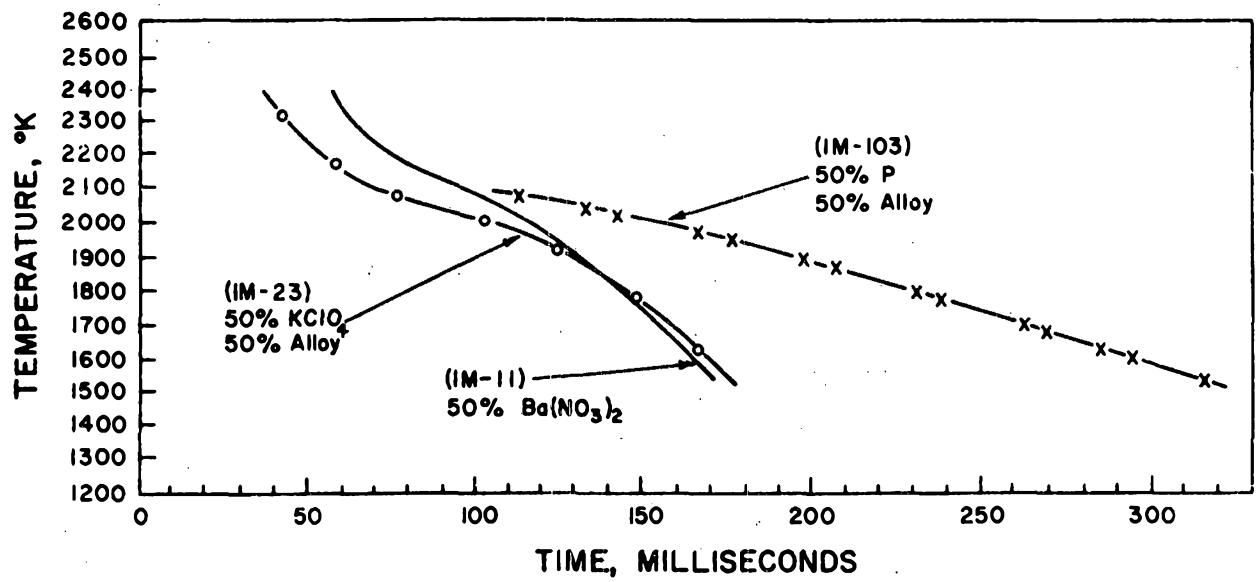


Figure 5-5. Time-Temperature Histories for IM-11, IM-23 and IM-103

Barium nitrate has been incorporated in over 200 incendiary mixtures, including the widely used IM-11 filler, and has been utilized in proportions ranging from one percent to 65 percent of the total mix. This oxidizer is stable to approximately 600°C, has a high critical humidity, is easily handled, and is available at moderate cost. Some compositions in which barium nitrate is used as the primary oxidizer are improved, from the standpoint of incendiary functioning, by the addition of a small quantity of a more reactive oxidizer such as ammonium nitrate or potassium perchlorate. Ammonium nitrate has been used in several incendiary mixtures as an oxidizer, however, it has a relatively low decomposition temperature and tends to sensitize incendiary mixtures in which it is used. Other nitrates are potentially good oxidizers, but are not widely used because of some undesirable characteristic, such as being relatively hygroscopic or uneconomical.

The alkali metal perchlorates are the second most widely used group of oxidizers for incendiary mixtures.[2] Potassium perchlorate has been used in many incendiary fillers in proportions varying from 2.5 percent to 75 percent of the total mixture. Potassium perchlorate has essentially the same total and available oxygen content as barium nitrate but exhibits a lower decomposition temperature. Mixtures containing potassium perchlorate tend to be more sensitive and to burn faster than mixtures which contain only barium nitrate as the oxidizer. Ammonium perchlorate has also been used as an oxidizer. This material is considered to be an explosive since the hydrogen contained in the compound can be oxidized rapidly as the decomposition of ammonium perchlorate takes place. This oxidizer-explosive has been used extensively in the MOX series of metalized explosives and probably contributes to the explosive energy of these compositions, as well as providing oxygen for the burning of the metallic fuel which provides the major incendiary effect of MOX-loaded ammunition. Ammonium perchlorate is a rather sensitive oxidizer and, therefore, is somewhat hazardous to handle. Other perchlorates have been used; but, in general, they are hygroscopic and, therefore, are difficult to handle in production loading equipment.

Some peroxides and less stable oxides can be used as oxidizers in incendiary mixtures. Lead dioxide is probably the most important member of this group, and it has been used in several incendiary fillers. It tends to sensitize mixtures in which it is used, although by itself it is safe

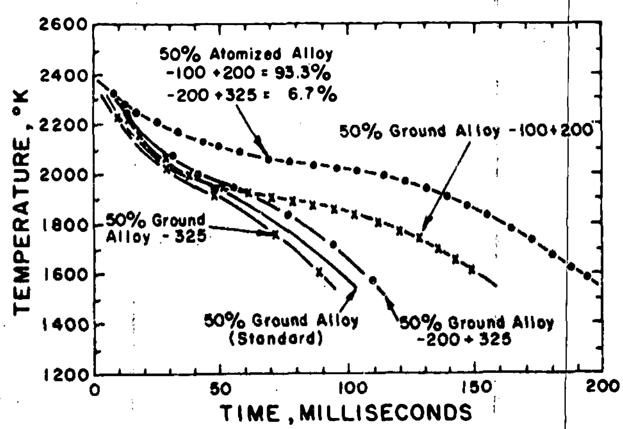


Figure 5-6. Cooling Curves for Mixtures Containing Various Particle Sizes and Shapes of Magnesium Aluminum 50/50 Alloy

and easy to handle. Less oxygen is available from lead dioxide than from many of the nitrate and perchlorate oxidizers. Its high density has made lead dioxide useful for applications where an increase in bullet weight is desirable.

A few additional oxidizers that have been evaluated in incendiary mixtures are worthy of mention. These include potassium chlorate, which is a relatively good oxidizer except for its sensitivity and incompatibility with certain fuels, notably red phosphorus; strontium chromate, potassium dichromate, and potassium permanganate have also been used. None of these has been found to be fully satisfactory as oxidizers for incendiary mix applications.

One of the most intriguing applications of oxidizing materials to the destruction or damaging of aircraft structures is the direct reaction of an oxodizing agent with the fuel contained in the aircraft. The idea is appealing because of the potential chemical energy release since only oxygen or an oxidizing agent is placed in the projectile and no space is required for fuel. Many rather difficult practical problems are involved in adapting this principle to realistic target conditions using standard projectile components and fuzing mechanisms. Some of the oxidizing chemicals which might be useful in this connection include IF_5, ClF_3, BrF_3, $HClO_4$, OF_2, O_2F_2, O_3F_2, NO_3F, ClO_2F, and NF_3.

5-4.1.3.3 Binders, Lubricants, and Other Incendiary Mixture Additives

The first metal-fuel incendiary compositions used in small arms ammunition contained only the metal-fuel and a suitable oxidizer. The mass production of small arms incendiary ammunition during World War II created problems concerning pelleting of incendiary mixtures, sticking of compression punches, lumping of mixtures during handling, and failure of mixtures to flow properly in the automatic loading equipment. These problems were met by adding binders, lubricants and flow promoters to the then standard compositions. The amount of additive present in the compositions was small and did not impair the incendiary functioning of the ammunition, and they were essential to the successful mass production of incendiary ammunition. Without these additives it would have been impossible to achieve the high level of ammunition quality that was maintained during World War II. Since then, the requirements for mass produced ammunition have become even more stringent.

The two most frequently used binders in small arms incendiary mixtures are calcium resinate and asphaltum. In incendiary filler compositions, calcium resinate is used in amounts varying between one and two percent, and asphaltum is used in amounts varying between one and five percent. A number of other binders have been tested in several compositions from time to time. These include Acrawax, dextrin, starch, nitrocellulose, gum arabic, polyvinyl alcohol, red gum, vistanex (a rubber preparation), and AP-2 (a jellied gasoline and aluminum mixture).

Graphite, in a range of particle sizes, has been used successfully as a lubricant to prevent the sticking of pelleting and compression punches during the loading of incendiary ammunition. This lubricant is normally added in amounts ranging from 0.25 percent to 2.0 percent. Stearates of zinc and aluminum have been employed in a number of small arms incendiary compositions to prevent lumps from forming in the mixtures and to improve the flow characteristics during the automatic loading processes. These ingredients are of some assistance in forming pellets of the mix in addition to their flow-inducing characteristics. Zinc stearate

TABLE 5-7
TYPICAL SMALL ARMS INCENDIARY MIXTURES

IM-11
50% Magnesium-Aluminum Alloy (50/50)
50% Barium Nitrate

IM-21A
48% Magnesium-Aluminum Alloy (50/50)
48% Barium Nitrate
3% Calcium Resinate
1% Asphaltum

IM-23
50% Magnesium-Aluminum Alloy (50/50)
50% Potassium Perchlorate

IM-28
50% Magnesium-Aluminum Alloy (50/50)
40% Barium Nitrate
10% Potassium Perchlorate

IM-68
50% Magnesium-Aluminum Alloy (50/50)
25% Ammonium Nitrate
24% Barium Nitrate
1% Zinc Stearate

IM-69
50% Magnesium-Aluminum Alloy (50/50)
40% Barium Nitrate
10% Iron Oxide (Fe_2O_3)

IM-112
45% Magnesium-Aluminum Alloy (50/50)
5% Tungsten Powder
50% Barium Nitrate

IM-136
49% Magnesium-Aluminum Alloy (50/50)
49% Potassium Perchlorate
2% Calcium Resinate

IM-139
10% Magnesium-Aluminum Alloy (50/50)
40% Red Phosphorus
47% Barium Nitrate
3% Aluminum Stearate

IM-142
46% Magnesium-Aluminum Alloy (50/50)
48% Barium Nitrate
5% Asphaltum
1% Graphite

IM-214
50% Zirconium (60/80) (lot 6)
25% Magnesium-Aluminum Alloy
25% Potassium Perchlorate (—250)

IM-241
50% Zirconium (20/65)
25% Magnesium-Aluminum Alloy
25% Potassium Perchlorate (—250)

IM-385
49% Magnesium-Aluminum Alloy (50/50)
49% Ammonium Perchlorate
2% Calcium Resinate

MOX-2B (High Explosive Incendiary Fillers)
52% Aluminum Powder
35% Ammonium Perchlorate
6% RDX/Wax (97/3)
4% TNT (Coated on the Ammonium Perchlorate)
2% Calcium Stearate
1% Graphite

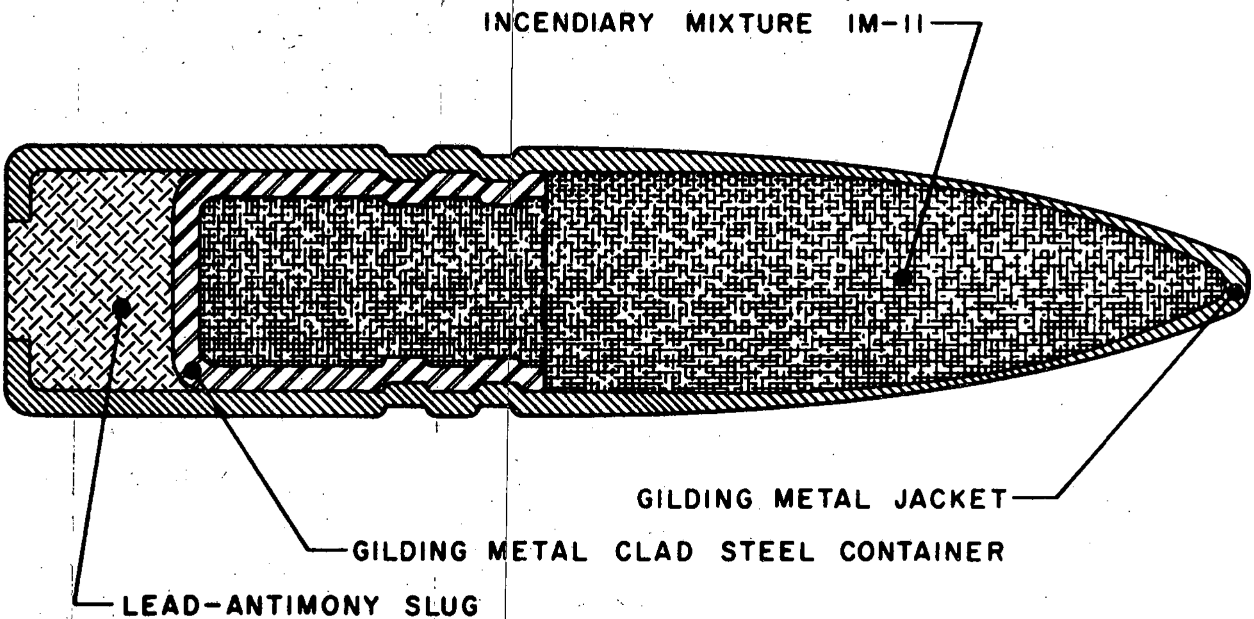
in the amounts of 1%-2% has been most widely used for this purpose. Aluminum stearate has also been employed for this purpose.

5-4.1.3.4 Typical Compositions

The compositions of 14 small arms incendiary mixtures, considered to be typical, are given in Table 5-7.

5-4.1.4 Typical Small Arms Incendiary Bullets

Typical incendiary rounds are shown in Figures 5-7 through 5-10. Illustrated are a caliber .50 incendiary bullet, Figure 5-7, and a caliber .50 armor-piercing incendiary, Figure 5-8. A 20 mm armor-piercing incendiary bullet is shown in Figure 5-9 and a 20 mm high explosive incendiary projectile is shown in Figure 5-10.



TOTAL WEIGHT: 512 GRAINS

Figure 5-7. Typical Caliber .50 Incendiary Bullet

5-4.2 INCENDIARIES FOR GROUND APPLICATION

Ground incendiaries include that class of munitions used for damage, mainly by combustion, to ground targets and are considerably larger than the small arms incendiaries previously discussed. Incendiary bombs, for example, are more effective against cities than high explosives, especially when antipersonnel features are included to delay fire fighting operations. The delay in fire fighting operations allows the smaller fires to grow and unite to form a conflagration which is almost impossible to control. In many cases, toxic effects resulting from the use of incendiaries or flame weapons (high carbon monoxide content-low oxygen content) cause many casualties. In some cases, the psychological fear prevents effective fire fighting operations and may result in the loss of equipment through abandonment.

Because progress in the development of incendiary and flame weapons for use against ground targets has been made mainly during times of stress, emphasis has been directed toward the development of weapons which could be rapidly put into the hands of combat troops. Little, if any, effort was directed toward studying those factors concerned with the initiation of destructive fires in various targets. As a consequence, less is known about the factors which might increase the effectiveness of incendiary munitions against ground targets than is known about the effectiveness of incendiaries against aircraft targets.

5-4.2.1 Ignition and Combustion of Ground Targets

Incendiary and other flame-producing weapons, like most weapons used against ground targets, are a source of energy which, when absorbed by the target, will cause damage. The amount of energy absorbed from the incendiary source by the target is not usually sufficient to produce appreciable damage but serves only to initiate combustion of the target in the oxygen of the air. Small fires started in this manner serve as ignition sources for the remainder of the target material, resulting in the spread of the fire. The ignition process and early growth of the fire are the critical stages in the development of a damage-producing fire.

To initiate burning of a target in air, three

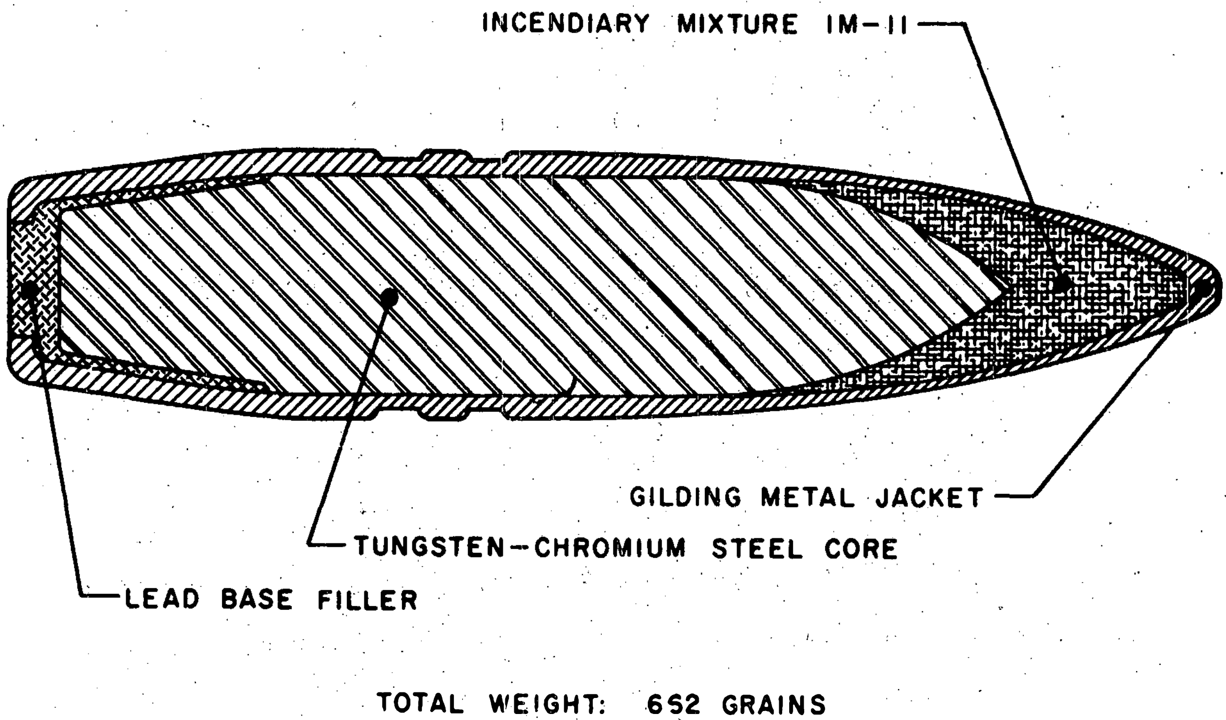


Figure 5-8. Typical Caliber .50 Armor-Piercing Incendiary Bullet

essentials must be provided, namely: (1) a source of heat to initiate the fire, (2) combustible material which serves as kindling, and (3) the fuel. All incendiary munitions, except those which are spontaneously combustible, must contain an initiator. The major part of an incendiary filling serves as the kindling and the target supplies the fuel. The efficiency of an incendiary depends on the total heat output and the rate of transfer of the energy to the target so as to initiate a sequence of events which will result in the burning of the target. Solid materials, such as wood, must be heated to a sufficiently high temperature in order to form the gaseous intermediates to react with the oxygen of the air. Liquid fuels, as discussed in detail in Paragraph 5-4.2.2.2.1, also must be vaporized before combustion is initiated.

5-4.2.2 Incendiary Compositions

Most of the research on incendiaries has been concerned with quantity and type of combustible used as an incendiary filler. Incendiary fillers can be basically classified into three categories: metal-based incendiaries, liquid fuel-based incendiaries, and a combination of these two. Fillings can also be classified into those which owe their incendiary effect to a self-supporting exothermic reaction and those which depend on atmospheric oxygen for their combustion.

5-4.2.2.1 Metal-Based Ground Incendiaries

Incendiaries containing metallic components are of two types: those which utilize the oxygen of the air in their combustion, and those in which an oxidizing agent furnishes the oxygen.

Magnesium-aluminum alloy used both as the case and in the composition of a four-pound incendiary bomb is an effective incendiary and was widely used in World War II in raids against German and Japanese cities. Reaction with oxygen of the air produces more heat with an incendiary metal than with solid oxidizing compounds. The use of these compounds, therefore, must be justified by an increase in effectiveness due to the higher rate of heat release.

Thermite-type incendiary mixtures are composed of approximate oxygen-balanced mixtures of reducing and oxidizing agents. While there are

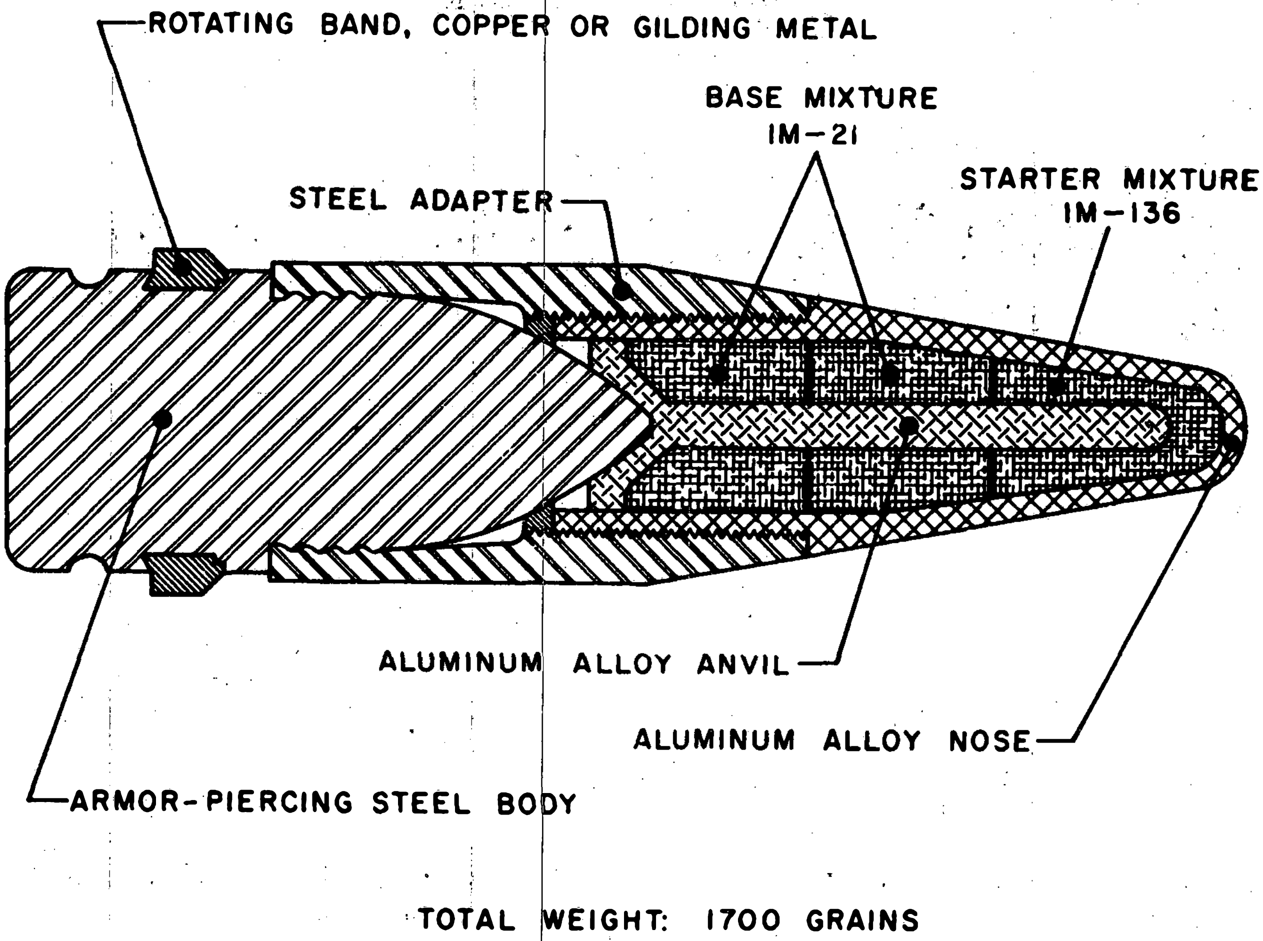


Figure 5-9. Typical 20 mm Armor-Piercing Incendiary Bullet

a large number of possible combinations which contain one or more reducing agents with one or more oxidizing agents; aluminum (Table 5-1) and, to a lesser extent, magnesium (Table 5-8) have been the only reducing agents used in thermite-type incendiary mixtures.

Military thermite for incendiary purposes is composed of 2.75 parts of iron oxide scale and one part of granular aluminum.[20] The reaction:

$$8Al + 3Fe_3O_4 \rightarrow 4Al_2O_3 + 9Fe + \Delta H$$

gives the stoichiometrical ratio of one part of aluminum to 3.2 parts of iron oxide, Fe_3O_4. Ferric oxide, Fe_2O_3, reacts as follows:

$$2Al + Fe_2O_3 \rightarrow Al_2O_3 + 2Fe + \Delta H$$

and gives the stoichiometrical ratio of one part of aluminum to 2.96 parts of ferric oxide. Ferrous oxide, FeO, reacts as follows:

$$2Al + 3FeO \rightarrow Al_2O_3 + 3Fe + \Delta H$$

and gives the stoichiometrical ratio of one part of aluminum to four parts of ferrous oxide. Since iron oxide scale (hammer scale) is a mixture of ferrous and ferric oxide in various proportions, the stoichiometric amount of aluminum required to react with the available oxygen present will also vary.

The ferrous oxide, FeO, content of the hammer scale has little effect on either the burning time or the penetration of the molten iron produced by the thermite reaction. A lower ferrous oxide content produces a considerably better flame and better propagation of burning; however, for values below 22 percent ferrous oxide, the improvement is slight. Thinner flake scales, such as pipe scale and rod scale, have been found to be more satisfactory than coarser scales; however, the use of a slight excess

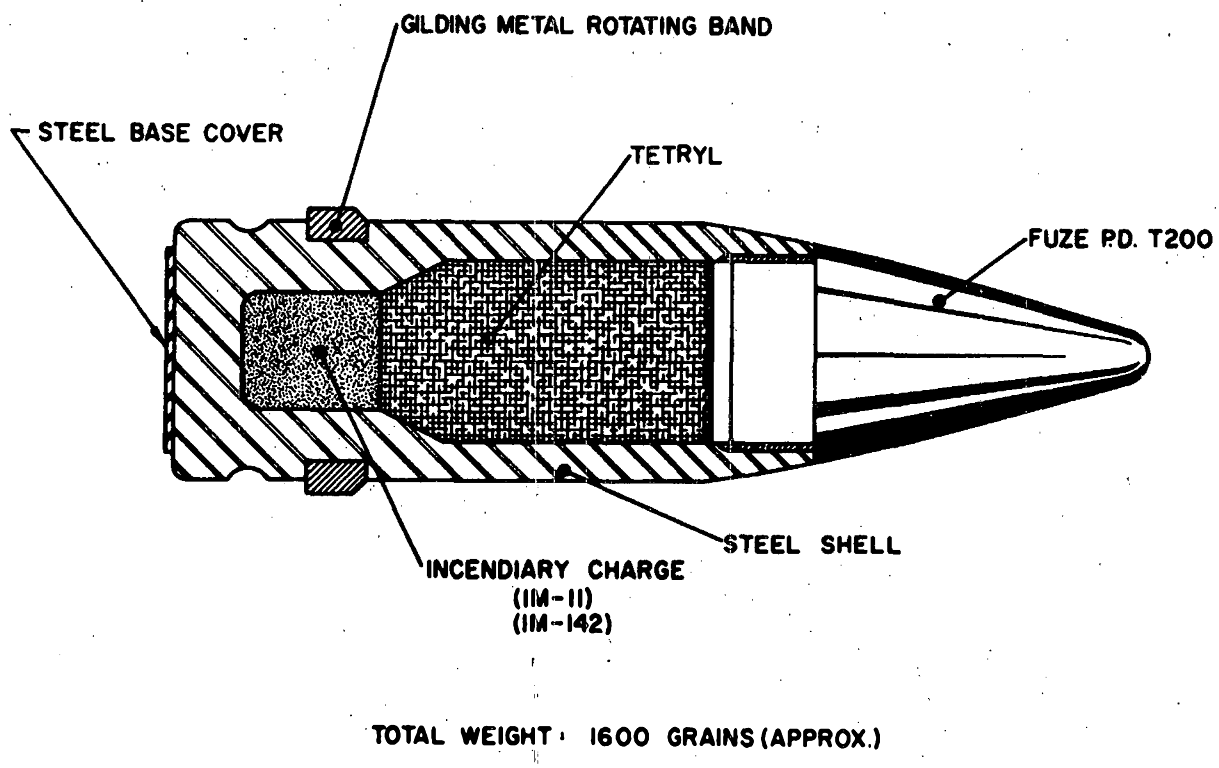


Figure 5-10. Typical 20mm High Explosive Incendiary Projectile

of aluminum minimizes the effect of particle shape of the hammer scale.

The use of low-purity aluminum (92.5 percent) requires a higher ratio of aluminum to hammer scale (1 to 2.7-2.8) to obtain optimum burning characteristics. The use of fine-mesh granular aluminum results in decreased burning times approaching a minimum limit with decrease in particle size. If the aluminum is too coarse, poor propagation, poor flame, and a longer burning time result.

During World War I, binders such as sodium silicate, sulfur or celluloid were added in order to reduce segregation of the thermite after loading; however, these techniques were only partially successful. Thermite has not been used since World War I for incendiary applications. While the heat released by a thermite mixture is sufficient to heat the products of reaction to around 3000°C, the incendiary action is confined to a relatively small area. In order to improve the incendiary effectiveness, several other incendiary compositions, including several modified thermite compositions, have been tried without appreciable success. The compositions of some of the incendiary mixtures tried are given in Table 5-9.

5-4.2.2.2 Liquid Fuel-Based Incendiaries

Liquid fuel incendiaries depend entirely upon the oxygen of the air for their combustion. The organic substance with the highest heat of combustion on a volume basis is anthracene with 11,900 calories per milliliter. A wide variety of natural oils and waxes fall in the range of 8,500 to 9,200 calories per milliliter. For hydrocarbons, there is a definite relationship between the heats of combustion and the hydrogen-carbon ratio as shown in Table 5-10. The order of heat on a unit-volume basis is the inverse of the order of the hydrogen-carbon ratios, while the position is reversed on a unit-weight basis. While the heat evolution per unit-volume of n-octane is comparatively low, its heat evolution per unit-weight is very high (11,-500 calories per gram), being exceeded only by boron and beryllium on this basis.

TABLE 5-8
HEAT OF REACTION OF THERMITE-TYPE MIXTURES CONTAINING MAGNESIUM

Mixture	*Heat of reaction, cal/g*
$Mg + Sb_2S_3$	507
$5Mg + Ba(NO_3)_2$	1,636
$4Mg + BaSO_4$	1,046
$4Mg + CaSO_4$	1,529
$3Mg + Fe_2O_3$	1,030
$4Mg + Fe_3O_4$	956
$2Mg + FeS_2$	764
$Mg + PbO$	378
$2Mg + PbO_2$	789
$4Mg + Pb_3O_4$	736
$5Mg + PbSO_4$	1,054
$4Mg + MgSO_4$	1,661
$2Mg + MnO_2$	1,248
$5Mg + 2KNO_3$	793
$4Mg + KClO_4$	2,442
$9Mg + K_2S_2O_8$	1,870
$4Mg + K_2SO_4$	1,916
$4Mg + Na_2SO_4$	1,060

5-4.2.2.2.1 Liquid Incendiaries

Liquid incendiaries such as petroleum oils, carbon disulfide, wood-distillation products, and other flammable liquids, were tested during World War I. These materials all had the drawback of excessive dispersion; to overcome this, the liquids were absorbed in some material such as cotton waste, but this method was only fairly satisfactory. During World War II this idea was revived and, based on development work, 14 percent cotton waste saturated with 86 percent of a 50/50 mixture of gasoline and fuel oil was tried as a possible filling for incendiary bombs, but was discontinued as more effective fillers became available.

5-4.2.2.2.2 Solidified Liquid Incendiaries

Because of the high degree of dispersion and consequent flash burning of liquid incendiaries, many substances have been proposed for solidifying liquid incendiaries. These include:[21]

a. Fatty acid derivatives
  (1) Aluminum, sodium, zinc, and ammonium salts
  (2) Lead salts of hydroxy acids
  (3) Sulfonated products
  (4) Amides
  (5) Fatty acids *per se*
  (6) Natural waxes
    (a) Nitrated
    (b) Sulfonated
    (c) *Per se*
  (7) Anilides

b. Polyhydroxy derivatives
  (1) Glycol compounds: Esters of fatty acids
  (2) Ethanolamine compounds
    (a) Esters of fatty acids
    (b) Compounds of mono-, di-, and triethanolamine
  (3) Glycerol compounds

TABLE 5-9
MODIFIED THERMITE COMPOSITIONS

Constituents	*Composition, Percent*				
	Therm-8	*Therm 8-2*	*Therm 64-c*	*Barytes Thermite*	*Calcium Sulfate Thermite*
Iron Oxide Scale	61	55.2	44	59.2	—
Aluminum	22.8	25	25	25.3	40.9
Barium Nitrate	15	19.5	29	—	—
Sulfur	0.90	—	2	—	1.0
Castor Oil	0.30	0.30	—	—	0.3
Barium Sulfate	—	—	—	15.3	—
Calcium Sulfate	—	—	—	—	57.8

TABLE 5-10
HEATS OF COMBUSTION AND HYDROGEN-CARBON RATIOS OF SELECTED FUELS

Hydrocarbon	*Hydrogen-Carbon Ratio*	*Calories per ml*	*Calories per g*	*Density, g/u*
Anthracene	0.72	11,900	9,500	1.25
Naphthalene	0.80	11,000	9,600	1.15
Toluene	1.14	8,800	10,200	0.866
Methylcyclohexane	2.00	8,600	11,100	0.769
n-Octane	2.25	8,100	11,500	0.706

(a) Saponified vegetable oil mixes
(b) Nitrated vegetable oils
(c) Vegetable oils *per se*

(4) Polysaccharide compounds
(a) Lactose anhydride
(b) Dextrins
(c) Pectins

(5) Cellulose esters
(a) Ethyl cellulose (7 to 10 percent)
(b) Pulp

c. Resinous derivatives
(1) Natural
(a) Alkali-treated resin
(b) Shellac
(c) Damar
(d) East India fossil
(e) African fossil
(f) New Zealand fossil
(2) Synthetic: Saponified polyacrylates

d. Hydrocarbon derivatives
(1) Paraffin
(2) Synthetic rubber
(3) Natural rubber
(4) Salts of sulfonated petroleum fractions
(5) Salts of naphthenic acid

e. Inorganic derivatives
(1) Organo-silicon compounds: Esters
(2) Bentonite
(3) Oil shale

Of these, only a few were ever found practical for use in thickening incendiary liquids. The most successful substances were:

a. Rubber (natural and synthetic)
b. Aluminum salts of mixed fatty acids and naphthenic acid
c. Polyacrylates

5-4.2.2.2.2.1 Rubber Thickeners

The addition of thickners—e.g., smoked rubber, crepe rubber, and latex—to gasoline produces an incendiary filling resembling sticky rubber cement. Fillings of this type are reasonably satisfactory; the material sticks to the target and burns slowly enough to allow an effective transfer of heat to the target. During World War II, however, rubber was in critically short supply and other thickeners had to be developed. Satisfactory thickeners can also be made with some synthetic rubbers.

5-4.2.2.2.2.2 Napalm Thickeners

The napalm thickener finally adopted consisted of a granular base aluminum soap of naphthenic, oleic, and coconut fatty acids. The sodium soap used for the precipitation of the aluminum soap contained 0.10 to 0.15 percent alpha-naphthol. The recommended formula of the organic acids used in making the napalm thickener was:

	Parts by weight
Coconut fatty acids	50
Naphthenic acid	25
Oleic acid	25

The aluminum content of the finished thickener

TABLE 5-11
COMPOSITION OF IM-TYPE INCENDIARY GELS

Code	IM Type 1	IM Type 2	IM Type 3	F-1416	F-1429	F-1431	F-1457
Constituent	*Composition, Percent*						
Isobutyl methacrylate polymer AE (IM)	5.0	5.0	2.0	3.0	3.0	3.0	3.0
Stearic acid	3.0	—	—	1.0	4.0	3.0	4.5
(Fatty acids)	—	2.5	3.0	—	—	—	—
Naphthenic acid	—	2.5	3.0	3.0	—	1.0	0.5
Calcium oxide	2.0	—	—	3.1	4.0	3.5	—
Caustic soda (40% solution)	—	3.0	4.5	—	—	—	—
Ammonium hydroxide (27% solution)	—	—	—	—	—	—	2.3
Gasoline	88.75	87.0	87.5	87.6	86.5	87.3	89.3
Water	1.25	—	—	2.3	2.5	2.2	—

ranges from 5.4 to 5.8 percent and the moisture content from 0.4 to 0.8 percent. Varying the composition of napalm from the standard to 2:1:1 ratio of coconut to oleic to naphthenic acid indicated that the viscosity of the gel increased primarily with increased oleic acids and, to a lesser extent, with increased coconut acid above normal composition. The acid number of the coconut acid was found important. Iron was an undesirable impurity when found in the alum but not in the acid. Impurities in napalm thickener which may cause partial or complete breakdown of gels formed with gasoline or oxidation of the thickener, include excess water, lime, caustic soda; soaps of sodium, copper, lead, iron, manganese, and cobalt; powdered or sheet zinc and lead; lead nitrate; rust preventatives containing amines, alcohols, and all acids. Tetraethyl lead, on the other hand, has no injurious effects.

The fundamental reactions may be expressed as follows (HR denotes the mixture of fatty and naphthenic acid):

$$6NaOH + 4HR + Al_2(SO_4)_3 \rightarrow 2Al(OH)R_2 + 3Na_2SO_4 + 4H_2O$$

$$6NaOH + 2HR + Al_2(SO_4)_3 \rightarrow 2Al(OH)_2R + 3Na_2SO_4 + 2H_2O$$

The soaps may hydrolyze:

$$Al(OH)R_2 + H_2O \rightarrow Al(OH)_2R + HR$$

$$Al(OH)_2R + H_2O \rightarrow Al(OH)_3 + HR$$

Because of hydrolysis, AlR_3 does not form, and fatty acid in excess of that required remains as such:

$$6NaOH + 6HR + Al_2(SO_4)_3 \rightarrow [2Al(OH)R_2 + 2HR] + 3Na_2SO_4 + 4H_2O$$

Three processes have been used successfully for the manufacture of napalm. All are based on the above equations, but the mechanical details for combining the materials differ.

Napalm, while a satisfactory thickener, is susceptible to oxidation by the atmosphere and is hygroscopic, resulting in a thickened gasoline with poor characteristics.

5-4.2.2.2.2.3 Methacrylate Thickeners

Satisfactory thickened gasoline could be made when 15-20 percent isobutyl methacrylate polymer (IM) was added. Some satisfactory IM gels are summarized in Table 5-11.

Low temperature stability is favored by a low polymer content, the use of polymer of low meth-

TABLE 5-12
COMPOSITION OF PT INCENDIARY MIXTURES

Code	*PT-1*	*PT-2*	*PT-3*
Constituent		*Composition, Percent*	
Goop	49.0	30.0	—
Isobutyl methacrylate polymer AE	3.0	—	—
Magnesium (coarse)	10.0	10.0	30.0
(50/50 Mg-Al alloy)			10.0
Sodium Nitrate	5.0	8.0	6.5
Gasoline	30.0	44.0	37.5
Petroleum Oil Extract	3.0	—	—
(Bright stock)			10.0
GR-S (Buna-S synthetic rubber)	—	8.0	6.0
Sulfur monochloride (S_2Cl_2)	—	0.2 (add)	0.2 (add)

acrylic acid content, a high soap content, a high concentration of gelling agent, a low water content, and the use of gasoline which has a low aniline point. With a reasonably stable basic formula, the most important factors appear to be the nature of the gasoline and the strength and concentration of the gelling agent. High temperature stability is favored by a high polymer content, a high stearic acid content, and the use of concentrated solutions of the gelling agent, i.e., a low water content. The presence of oxygenated solvents destroys high temperature stability.

In order to increase the effectiveness of the incendiary filling in starting fires in targets more difficult to ignite, a complex filling was developed having as its main constituent "goop", a mixture of magnesium particles and asphalt. To this was added gasoline, thickened with IM oxidizing agents and magnesium scraps. PT-1 composition, and the substitutes PT-2 and PT-3, used synthetic rubber instead of IM and an aluminum-magnesium alloy in place of "goop". (See Table 5-12.)

5-4.2.2.3 Other Incendiaries

Phosphorus and its compounds have been used as an incendiary against personnel and readily-ignitible materials. Burning phosphorus produces serious skin burns and tends to demoralize attacked troops. Because white phosphorus has a low combustion temperature, it is relatively ineffective against any but the most easily ignitible targets. The alkali metals, especially sodium, have been used as incendiaries but the results have not been satisfactory.

5-4.2.3 Typical Incendiary Devices

The principal military characteristic of an incendiary device is its ability to initiate combustion of material with which it comes in contact, and to provide the energy to maintain the combustion process and assist in enlarging the area over which combustion takes place. This characteristic is called fire raising power. Other military characteristics covering tactical use, provision of fire-fighting deterrents, and design details are also specified.

The four-pound magnesium alloy bomb, shown in Figure 5-11, was used during World War II in tremendous quantities. Its hexagonal shape adapted it to assembly in clusters for shipping and loading on planes. After dropping from the planes the bombs were separated from the clusters and widely dispersed in random manner. The explosive charge in the base was exploded by the heat, providing a deterrent to fighting the fire. Only a portion of

the bombs had the high explosive charge; the others were constructed as shown in Figure 5-12.

A "fire bomb" using napalm-thickened gasoline as the incendiary filling is illustrated in Figure 5-13. An incendiary grenade, suitable either for combat use or for destruction of materiel, is illustrated in Figure 5-14. It is loaded with a thermate, and is provided with an igniting charge, specified as first fire mixture.

5-5 DELAY COMPOSITIONS AND HEAT POWDERS

Gasless pyrotechnic mixtures are used for producing a controlled amount of heat and for time delays in a number of military applications. These compositions, which are physical mixtures of certain metals with one or more powdered oxidizing agents, react at a predetermined rate when ignited by the application of heat or flame. Their combustion is characterized by high reaction temperatures and the formation of mainly solid products. Both the burning rate and calorific output can be varied over fairly wide ranges by controlling the properties and proportions of the ingredients. Since little gas is produced by the combustion of these mixtures, atmospheric oxygen is not required for combustion, and the reaction rate is not greatly influenced by pressure; "gasless" compositions are particularly valuable for use in armament, e.g., in short delay bomb fuzes.

5-5.1 PYROTECHNIC DELAYS

Some ordnance items are more effective if functioning is delayed for an interval of time after the initiating stimulus. While a variety of mechanical and electrical devices[29] have been employed for this purpose, a time delay can be obtained by incorporating a pyrotechnic delay element into an explosive train. The time delay, in this case, depends on the length and rate of burning of the delay composition. Time delays can also be obtained by controlling the rate of heat flow through a thermal barrier,[30] or by the rupture of a barrier by the build-up of gas pressure.[31]

5-5.1.1 Delay Elements

A delay element is a self-contained pyrotechnic device consisting of an initiator, delay column, and an output terminal charge or relay; all assembled into a specially designed inert housing. In some designs, one or more of these components may be omitted. In some cases, depending on the application and delay composition, the delay element may also include baffles, a housing, and provision for an internal free volume. Based on their construction, pyrotechnic delays can be subdivided into two general types, obturated or vented.[29]

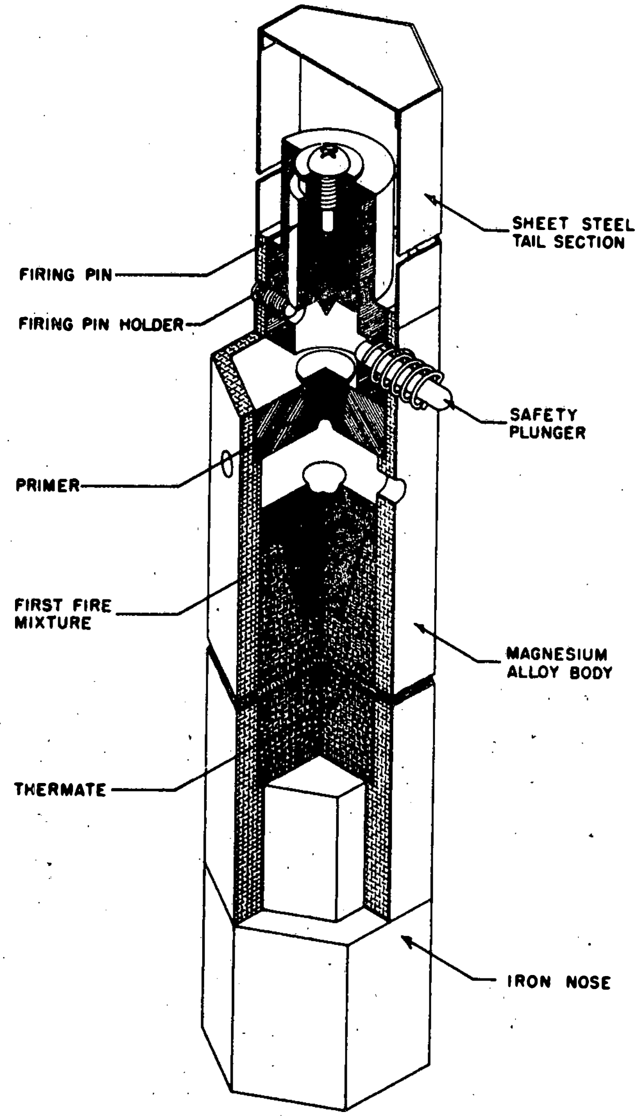


Figure 5-11. Four-Pound Magnesium Alloy Incendiary Bomb

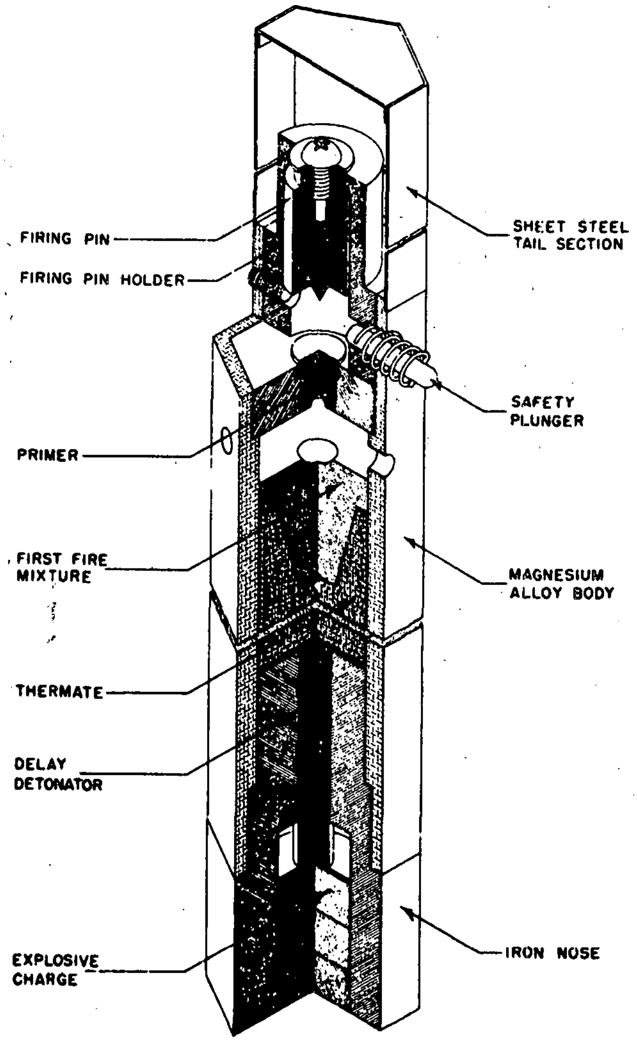


Figure 5-12. Four-Pound Thermite Incendiary Bomb

5-5.1.1.1 Obturated Delay Elements

An obturated delay element, as shown in Figure 5-15, is constructed to contain all of the gases produced by the functioning of the initiator and delay composition before the functioning of the terminal charge. Delays in which the gases produced are internally vented into a closed chamber in the explosive device are considered to be obturated. Because they are sealed, obturated delays are not influenced by the effects of the ambient pressure or humidity. The combustion products are contained which prevents possible harm to other components of the device. Short time delays are often obturated as obturation tends to increase the average burning rate of the delay composition.

5-5.1.1.2 Vented Delay Elements[80,82]

Vented delay elements have openings through which the gases produced by the functioning may escape. Vented delays are used when large quantities of gas are produced by the burning of the delay powder and may even be necessary for "gasless" mixtures when long delay times are required in order to eliminate pressure buildup within the delay element. Venting exposes the burning delay composition to ambient pressure. As a consequence, the burning rate of the delay mixture is sensitive to changes in altitude. In addition, these vents require sealing up to the time of functioning in order to protect the delay composition from humidity. Two methods for sealing vented delays are illustrated in Figure 5-16.

Another vented delay is the time ring which consists, as shown in Figure 5-17, of a column of fuze powder which is pressed into the fuze cavity. Because of its construction, the ring delay occupies a large part of the total fuze volume. With a ring delay the delay time can be set to any desired value within its time range by rotating a calibrated ring which varies the length of the delay train that must be burned before the terminal charge functions.

5-5.1.2 Delay Compositions

The delay compositions, being a critical part of the delay element, should ideally have certain characteristics which may be summarized as follows:

a. The ingredients should be stable and nonhygroscopic; should have the highest purity consistent with requirements; should be readily available and inexpensive; and should be compatible with each other.

b. The compositions should be capable of being blended, loaded, and assembled into an item with minimum risk from impact, friction, moisture, heat, and electrical discharge.

c. They should be readily ignitible, and should change little in performance characteristics with small changes in percentages of ingredients. Their burning rates should be reproducible within each batch and from batch to batch with a minimum of variation.

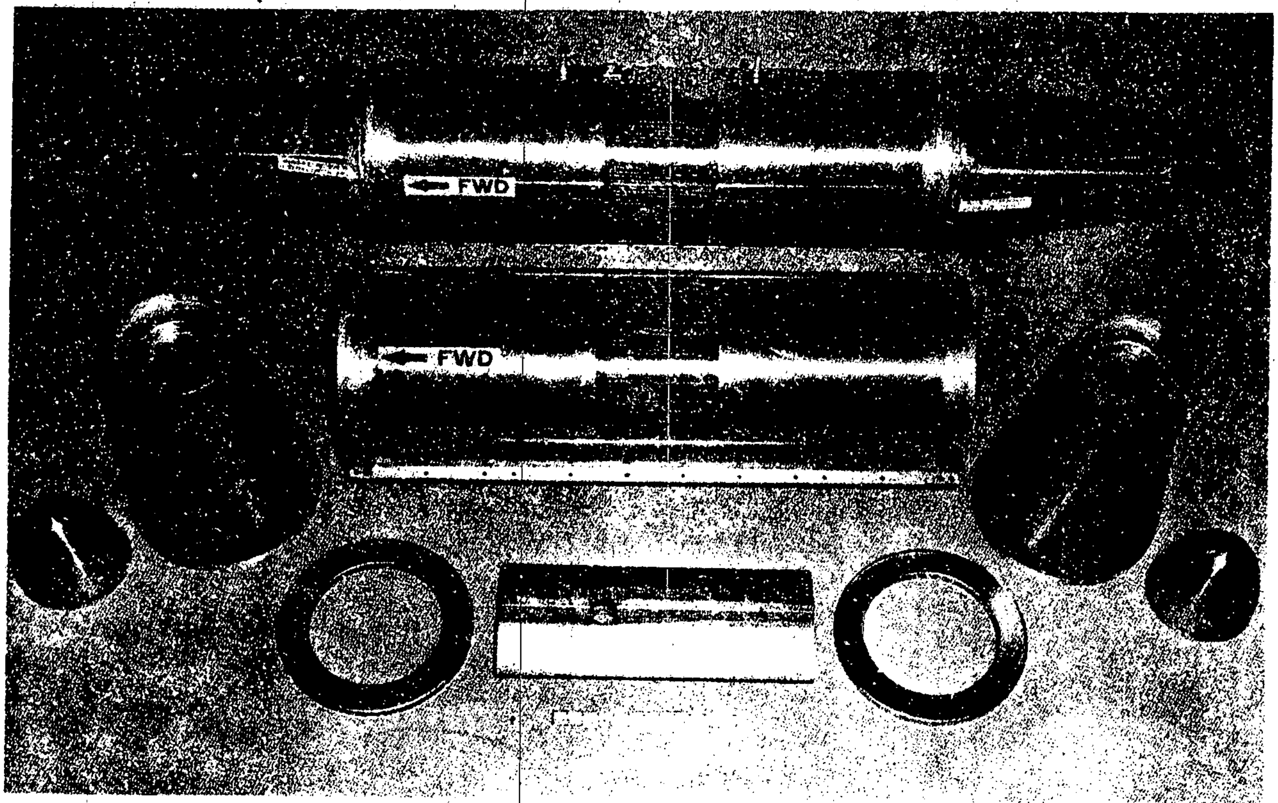


Figure 5-13. Typical Napalm Bomb

d. They should be compatible with their container as well as with other contacting compositions. Performance characteristics should not change appreciably with long term storage.

e. They should be relatively insensitive to changes in pressure and temperature.

f. They should be capable of withstanding the vibration and shock of transportation, setback, rotation, and impact, and should be resistant to physical abuse inherent in the loading, and firing of ammunition.

5-5.1.2.1 Black Powder Delays

Black powder has been long and widely used as a delay material in spite of the fact that it does not meet many of the ideal characteristics for a delay composition. This popularity may be attributed largely to its good dry surveillance characteristics, its ease of ignition, its wide availability in reproducible quality and granulation, its ease of loading, and its versatility from the standpoint of delay times obtainable.

As already indicated, black powder produces gases on burning, and the burning rate is affected by pressure. Hence, the disposition of the gases is a primary consideration in design; delay elements using black powder are generally vented. The burning rate of black powder is affected by the rotational speed of the projectile and by the ambient pressure. A major shortcoming of black powder has been and still is its marked hygroscopicity. As has been indicated earlier, because of these undesirables, gasless delay compositions were developed.

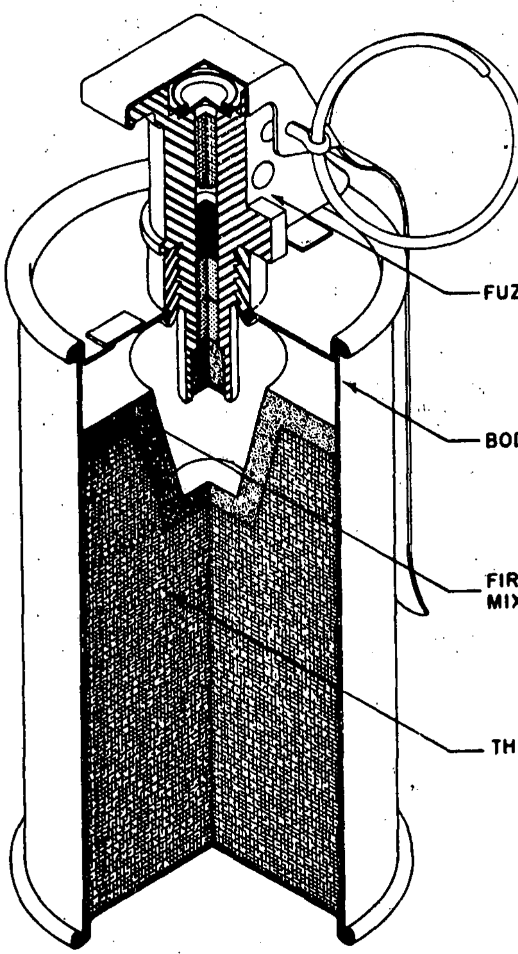


Figure 5-14. Typical Incendiary Grenade

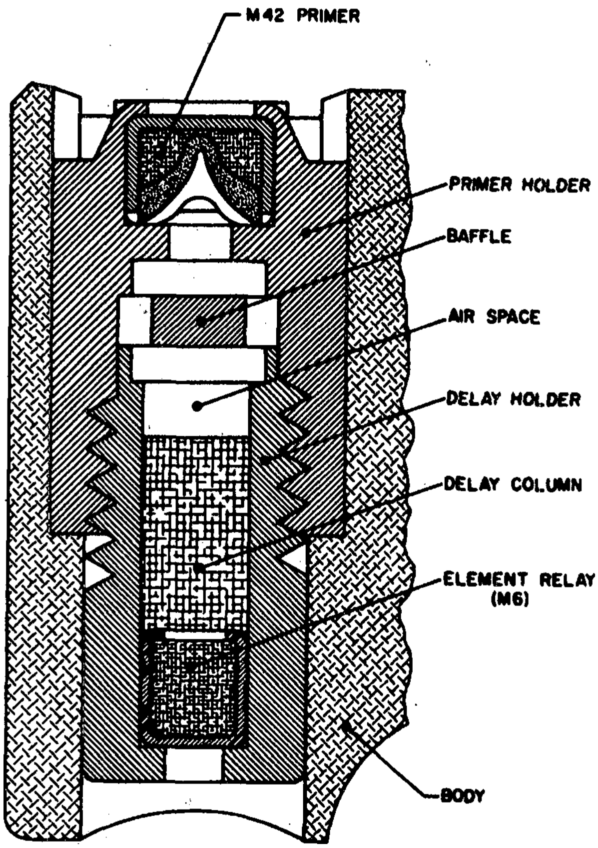


Figure 5-15. Obturated Delay Element

5-5.1.2.2 Typical Gasless Compositions

The gasless pyrotechnic mixtures which have been reasonably satisfactory for delays are given in Table 5-13. Different burning rates can be obtained by selecting a specific composition or by varying the proportions of ingredients in a composition.

The burning rates obtained with these compositions are given in Table 5-14. Under controlled laboratory conditions, the coefficient of variation of most of the compositions listed is three percent or less. Lot-to-lot variability may be compensated by adjusting the length of the delay column for each new lot of delay composition or by adding appropriate ingredients and remixing to speed up or slow down the mixture. Variation may be controlled by use of standardized raw materials and preparation procedures.

5-5.1.3 Factors Affecting Performance[36]

The propagative burning of a pressed column of a gasless delay composition is a combustion reaction in which the fuel and oxidizer react to give essentially solid products. The gases formed consist mainly of hydrogen, water, nitrogen, carbon monoxide, carbon dioxide, and traces of organic materials.[37] These gaseous products are produced as a result of the presence of impurities or for other reasons not directly related to the primary reaction. The observed velocities of the reaction have been justified; however, quantitative agreement was purely on the basis of thermal flow.[38,39]

Questions have been raised concerning the details of burning of gasless delay compositions. For some compositions, there is evidence that the formation of a gaseous phase plays an important part in the overall reaction mechanism while condensed phase reactions are important in the pre-

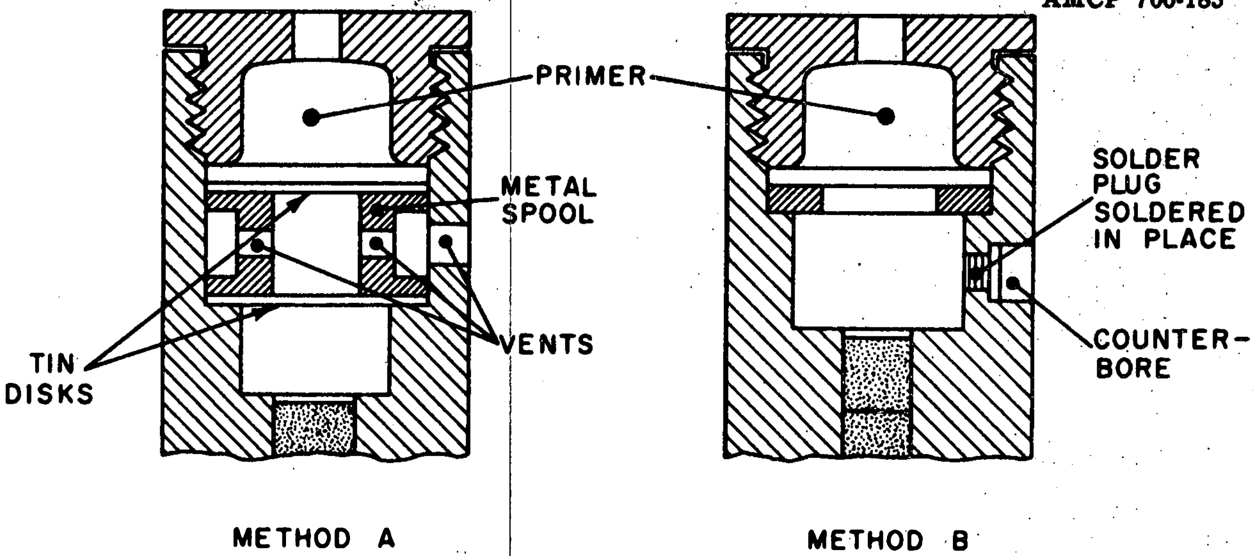


Figure 5-16. Sealing of Vented Delay Element

ignition reactions.[39,40,41,42,43] DTA and TGA studies of the ingredients in barium chromate-boron delay compositions do not, however, indicate the formation of a gaseous phase before ignition of the composition,[44] and that a gaseous phase may not be important, at least in this particular reaction.

In some cases the effectiveness of an explosive train depends greatly on the accuracy of the time delay produced by the burning of a delay column. While it is possible under controlled laboratory conditions to obtain coefficients of variation (Paragraph 5-5.1.2.2), less than three percent for many delay mixtures, the effect of ambient conditions and manufacturing variation in many cases is somewhat less than desirable. Factors which may influence the accuracy of a gasless pyrotechnic include:

a. Composition and Quantity of Charge
b. External Pressure
c. External Temperature
d. Terminal Charge
e. Particle Size
f. Ignition
g. Column Diameter
h. Loading Pressure
i. Housing Material
j. Acceleration
k. Storage
l. Processing

5-5.1.3.1 Composition

There are a large number of exothermal reactions between inorganic solids which yield little or no gaseous products. However, most of the reactions are not satisfactory for one or more of the following reasons:

a. Erratic burning rates
b. Large column diameter required for reliable propagation
c. Large temperature coefficient of burning rate
d. Failure at low temperatures
e. Hygroscopicity
f. Rapid deterioration
g. Unavailability of reproducible supply of raw materials
h. Large pressure coefficient of burning rate
i. Failure at low pressure

Reactions which were studied are summarized in Table 5-15.[24] Under the standardized conditions for these tests, it was found that for each oxidizing agent used, very fast burning times were obtained with magnesium, aluminum, zirconium, and titanium. Slower burning times were obtained with silicon, manganese, and chromium; while still slower ones occurred with iron, tungsten, and others. Metals which gave fast burning times with silver oxide, silver chromate, barium peroxide, and lead chromate gave slower burning times with cuprous oxide, barium chromate, and iron oxide.

The variation in burning rate for the barium

TABLE 5-13

GASLESS DELAY COMPOSITIONS IN CURRENT USE[83,84,85,50,51]

Fuel, %	*Oxidants, %*		*Inert, %*
Manganese	Barium Chromate	Lead Chromate	None
30 to 45	0 to 40	26 to 55	
Boron	Barium Chromate	Chromic Oxide	None
4 to 11	89 to 96	—	
13 to 15	40 to 44	41 to 46	
Nickel-Zirconium	Barium Chromate	Potassium Perchlorate	None
Alloy 26	60	14	
Nickel-Zirconium Mix	Barium Chromate	Potassium Perchlorate	None
5/31	22	42	
5/17	70	8	
Tungsten	Barium Chromate	Potassium Perchlorate	Diatomaceous earth
27 to 39	59 to 46	9.6	5 to 12
39 to 87	46 to 5	4.8	3 to 10
20 to 50	70 to 40	10	
Molybdenum	Barium Chromate	Potassium Perchlorate	
20 to 30	70 to 60	10	
Silicon	Red Lead		Diatomaceous earth
20	80		Max 8 parts by weight
Zirconium	Lead Dioxide		
28	72		

chromate-boron system as the percentage of boron in the composition was increased to 50 percent is summarized in Table 5-16.[83] As indicated by the data presented in this table, a sharp drop in burning time is obtained initially as the percentage of boron is increased. At approximately 10 percent boron, the burning rate levels off and remains nearly constant to approximately 25 percent boron, when it begins to decrease quite rapidly. The heat of reaction reaches a maximum at approximately 13 percent boron, which is a somewhat lower percentage than that composition (19 percent) producing the maximum burning rate. A plot of total heat evolved against burning times, Figure 5-18,[83] indicates that compositions with less than 11 percent boron burn slower than those containing more than 13 percent boron when the amount of heat evolved is the same.

5-5.1.3.2 External Pressure

As shown in Figure 5-19 for a 95.4% barium chromate-4.6% boron composition, an increase in the external pressure resulted in a decrease in burning times (an increase in burning rate). The relationship is hyperbolic and can be represented by an equation of the form:

$$t = ap^n \tag{5-11}$$

TABLE 5-14
BURNING RATES OF GASLESS DELAY COMPOSITIONS[33-36,51,52]

Composition	*Inverse Burning Rate, sec/in.*
$BaCrO_4/B$ (amorphous)	0.5-3.5
95/5	1.5
90/10	0.6
$BaCrO_4/B$ (crystalline)	9-12.5
$BaCrO_4/KClO_4$/Zr-Ni(70-30)/Zr-Ni(30-70)	3-11
60/14/9(70-30)/17(30-70)	6
60/14/3(70-30)/23(30-70)	11
$BaCrO_4/PbCrO_4/Mn$	2.5-12.5
30/37/33	9.45
35/33/42	12.5
Red Lead/Si/Celite	4-11
80/20/3 to 7 added	
$Zr/Ni/BaCrO_4/KClO_4$	
5/31/42/22	6.5
5/17/70/8	17.5
BaO_2/Se/Talc	
84/16/0.5 added	2.3 (approx)
PbO_2/Zr	
28/72	< 0.5
$BaCrO_2/Cr_2O_3/B$	4.5-8.5
44/41/15	4.5 (approx)
44/42/14	6.5 (approx)
$BaCrO_4/KClO_4/W$	
40/10/50	12.5 (approx)
60/10/30	31 (approx)
32/5/58	1
41/5/49	10
58/10/27	40

where t is the burning time in seconds, p is pressure in pounds per square inch, and a and n are constants. The numerical values of the constants are $n = 0.13$ and $a = 2.52$ for the 95.4/4.6 barium chromate-boron composition.

No significant change was found, see Figure 5-19, in the burning times for a 90/10 and 81/19 barium chromate-boron composition for pressures less than atmospheric.

Results obtained with other delay mixtures also indicated that the burning rate would increase slightly with increasing pressure above atmospheric. Results with mixtures which contained manganese, cobalt and a nickel-zirconium mixture as the fuel indicated that a change in composition of the atmosphere did not have a significant effect on the burning rate.[45]

5-5.1.3.3 External Temperature

As shown in Figure 5-20, the burning times for delay compositions were found to decrease with increasing temperature. For 90/10 barium chromate-boron, a plot of burning rate against the

* 2 rounds not ignited.

TABLE 5-15
HEATS OF REACTION OF INORGANIC MIXTURES
CONSIDERED FOR DELAYS

Metals	*Silver Oxide*		*Silver Chromate*		*Barium Peroxide*		*Lead Chromate*		*Cuprous Oxide*		*Barium Chromate*		*Iron Oxi*	
	$-\Delta H°$	$-\Delta H°/n$	$-\Delta H°$	$-\Delta H°/n$	$-\Delta H°$	$-\Delta H°/n$	$-\Delta H°$	$-\Delta H°/n$	$-\Delta H°$	$-\Delta H°/n$	$-\Delta H°$	$-\Delta H°/n$	$-\Delta H°$	$-\Delta$ /n
MAGNESIUM	139.1	69.6(I)	688.5	68.9(I)	126.7	63.4(I)	560.7	56.1(I)	103.6	51.8(5)	292.9	48.8(5)	239.8	40.0
ALUMINUM	378.0	63.0	1869.0	62.3	340.8	56.8(I)	1485.6	49.5	271.5	45.3	253.6	42.3(N)	200.5	33.4
ZIRCONIUM	244.1	61.0	1206.5	60.3	219.7	54.9(I)	950.9	47.5	173.1	43.3	483.5	40.3	377.3	31.4
TITANIUM	211.0	52.8	1041.0	52.1	186.2	46.6(I)	785.4	39.3(5)	140.0	35.0	384.2	32.0	278.0	23.2
SILCON	187.0	46.8	921	46.1(N)	164.8	41.2(I)	665.4	33.3	116.0	29.0(N)	312.2	26.0(12)	206.0	17.2(N)
MANGANESE	89.5	44.8	440.5	44.1	77.1	38.6(4)	312.7	31.3	54.0	27.0(10)	144.1	24.0(23)	91.0	15.2(N)
CHROMIUM	252	42.0(N)	1239	41.3(N)	214.8	35.8(5)	855.6	28.5	145.5	24.3	63.8	21.3	74.5	12.4
ZINC	76.5	38.3	374.5	37.5	63.9	32.0	247.7	24.8	41.0	20.5	104.6	17.4	52.0	8.7
TIN	124.1	31.0	606.5	30.3	99.3	24.8	350.9	17.5	53.1	18.3	128.5	10.3	17.8	1.4
IRON	177.5	29.6(8)	866.5	28.9(8)	140.3	23.4	483.1	16.1(11)	71.0	11.8(N)	53.1	8.9(N)	0	0
CADMIUM	58.2	29.1	284	28.4	45.8	22.9	156.2	15.6	22.7	11.4	50.2	8.4	-2.9	-0.5
TUNGSTEN	174.7	29.1	852.5	28.4	137.5	22.9	469.1	15.6	68.2	11.4	50.3	8.4		
MOLYBDENUM	155.5	25.9	759	25.2	118.3	19.7	373.1	12.4(17)	49.0	8.2	31.1	5.2		
NICKEL	50.5	25.3	250.0	25.0	39.0	19.5	122.2	12.2	15.9	8.0	29.8	5.0		
COBALT	51.4	25.7	245.5	24.6	38.1	19.1	117.7	11.8	15.0	7.5	27.1	4.5		
ANTIMONY	145	24.2	704.0	23.5(10)	107.8	18.0(6)	320.6	10.7	38.5	6.4	20.6	3.4		
BISMUTH	116.1	19.4	544.0	18.1	78.9	13.2	176.1	5.9	9.6	1.6	-8.8	-1.4		
COPPER	31.5	15.8	150.5	15.1	16.4	8.2	22.7	2.3			-29.9	-5.0		
NONMETALS														
PHOSPHORUS	195	39(I)	192.4	38.5(I)	487.6	48.8(I)	128.4	25.7(2)	213	21.3	552.8	18.4(6)	35.3	7.1(15)
SULFUR	142.1	23.7	682.5	22.8(4)	158.2	26.4(4)	101.2	16.9(9)	95.9	4.8	28.8	4.8	-15.1	-0.5
SELENIUM	67.9	11.3	311.5	10.4	86.6	14.4	31.3	5.2	-6.2	-0.3				

$-\Delta H°$ HEAT OF REACTION.
$-\Delta H°/n$ EQUIVALENT HEAT OF REACTION (HEAT OF REACTION PER ELECTRON CHARGE).
(N) NO REACTION OBSERVED.
(I) VERY FAST BURNING RATE.
( ) BURNING TIME, SECONDS

logarithm of the absolute temperature results in a straight line. For the 95.4/4.6 compositions, this is also true for most of the temperature range; however, for some 95.4/4.6 compositions, there is a departure from this type of relationship at the lower temperatures. Over the narrower temperature range (−60°F to 160°F), the burning rate is essentially a linear function of the $\log_{10}$ temperature.

5-5.1.3.4 Terminal Charge, Anticipatory Effect[46]

The burning characteristics of pressed delay compositions are different when loaded above a thermally-sensitive terminal charge. The overall burning time and the reproducibility are both decreased under these conditions. This anticipatory effect has been observed with a variety of thermally-sensitive terminal charges for both gaseous and nongaseous delay compositions. The effect has also been observed for typical end item delay elements having a lead styphnate-lead azide relay.

The extent of the reduction in burning time that occurs with delay elements having thermally-sensitive terminal charges, compared with similarly pressed delay columns without a terminal charge, approaches a constant value as the length of the delay column above the terminal charge increases. The magnitude of this reduction in burning time for several barium chromate-boron compositions is a function of the burning rate of the composition. (See Table 5-17.) As shown in Table 5-18 the reduction in burning rate is less for the more rapid burning compositions. Obturation of the delay column substantially increases the magnitude of the anticipatory effect. The anticipatory effect is reduced by barriers, between the delay column and the thermally-sensitive terminal charge, which would reduce the flow of gases. The importance of gas permeation in the burning of pressed delay compositions is indicated.

5-5.1.3.5 Particle Size

The effect of particle size on the inverse burning rates of delay compositions follow a nearly direct proportionality. In addition to increasing the burning rate, reduction of the particle size tends to reduce the effects of temperature and pressure. This effect is shown to a marked degree by tungsten delay compositions, as is shown in Table 5-19. Although the percentage compositions are not identical, they are close enough that little difference in burning time would be observed if the tungsten fuel had the same surface area. The weight, average diameter, and the surface area

TABLE 5-16
EFFECT OF PERCENT COMPOSITION ON BURNING TIME, HEAT OF REACTION, AND IMPACT VALUES OF THE BARIUM CHROMATE-BORON SYSTEM

% Boron	Charge Wt, mg	No. Results Avg and Range Based on	Avg Burning Time, sec	Range, sec	Range, sec/sec B.T.	Heat of Reaction		Total Cal in Loaded Fuze	Cal/sec	Impact Test PA, inches
						Cal/g	Volume gas ml/g			
3.0%	2130	5	7.56	0.469	0.620	Incomplete reaction				40+
3.5%	2150	4	3.54	0.070	0.020	278	5.0	597	169	40+
4.0%	2140	4	1.72	0.031	0.018	354	5.0	768	446	40+
4.5%	2125	5	1.44	0.040	0.028	400	4.0	850	590	39
5.0%	2130	5	1.09	0.035	0.032	420	8.0	895	821	40+
6.0%	2110	5	0.767	0.021	0.027	231	8.4	909	1186	37
7.0%	2000	4	0.653	0.010	0.015	453	6.4	906	1387	38
8.0%	2000	4	0.560	0.001	0.002	462	7.9	924	1650	28
9.0%	2000	4	0.539	0.002	0.004	474	7.5	948	1758	29
10.0%	1975	4	0.465	0.015	0.032	515	7.3	1017	2187	21
11.0%	1925	4	0.432	0.020	0.046	536	6.9	1032	2388	18
13.0%	1900	4	0.397	0.006	0.015	556	8.9	1056	2661	20
15.0%	1875	4	0.382	0.027	0.071	551	7.0	1033	2704	16
17.0%	1800	4	0.375	0.027	0.072	543	11.6	977	2606	13
19.0%	1750	4	0.366	0.021	0.057	535	8.8	936	2558	16
21.0%	1685	4	0.375	0.007	0.019	526	8.6	886	2363	34
23.0%	1650	4	0.407	0.023	0.057	503	4.2	830	2703	40
25.0%	1625	4	0.433	0.025	0.058	497	10.2	808	1865	40+
30.0%	1611	4	0.574	0.025	0.044	473	10.4	762	1328	40+
35.0%	1500	4	0.965	0.115	0.119	446	12.7	669	693	40+
40.0%	1430	4	2.19	0.110	0.050	399	14.1	571	261	40+
45.0%	1360	3	5.25*	0.210	0.040	364	15.0	495	94	40+
50.0%	1290	2	14.5*	1.000	0.069	Incomplete reaction				40+

*2 rounds not ignited

were determined on the micromerograph. Under these experimental conditions, a fuel with about twice the surface area will have a linear burning time of about one-fifth of the former.

For the 90/10 barium chromate-boron composition, the use of boron of 1, 13.5, and 53 micron average particle size resulted in an increase in the inverse burning rate of 0.45, 6.61 and 9.53 seconds per inch, respectively. Similar results were observed for manganese delays.[35]

In addition to the average particle size, the particle size distribution and blending of delay mixtures is important if reproducible burning rates are to be obtained.[47] For the barium chromate-boron composition, there appears to be little difference between delay mixtures produced by wet and dry blending methods. Wet blending is preferred for safety reasons.

5-5.1.3.6 Ignition Compositions

Some gasless delay compositions are difficult to ignite. It is the usual practice to press a small charge of an igniter composition on top of the delay column, which is easy to ignite and is capable, in minimum quantities, of igniting the delay column. The complex interactions between initiating source and igniter and, in turn, igniter and main charge are yet to be determined. For the most part, igniters have been and still are selected on an arbitrary basis. Compositions of some of the ignition powders which have proved relatively satisfactory are given in Table 5-20. These mixtures are also gasless.

5-5.1.3.7 Column Diameter

Radial losses of heat can retard or extinguish the reaction in a delay column. Such losses become more serious as the column diameter, burning rate, and ambient temperature are reduced. These effects combine to result in a failure diameter associated with a given delay mix for a given ambient condition. For manganese delay compositions at $-65°F$, the failure diameter for a three-second per inch composition is less than 0.109 inch;

1266/1710

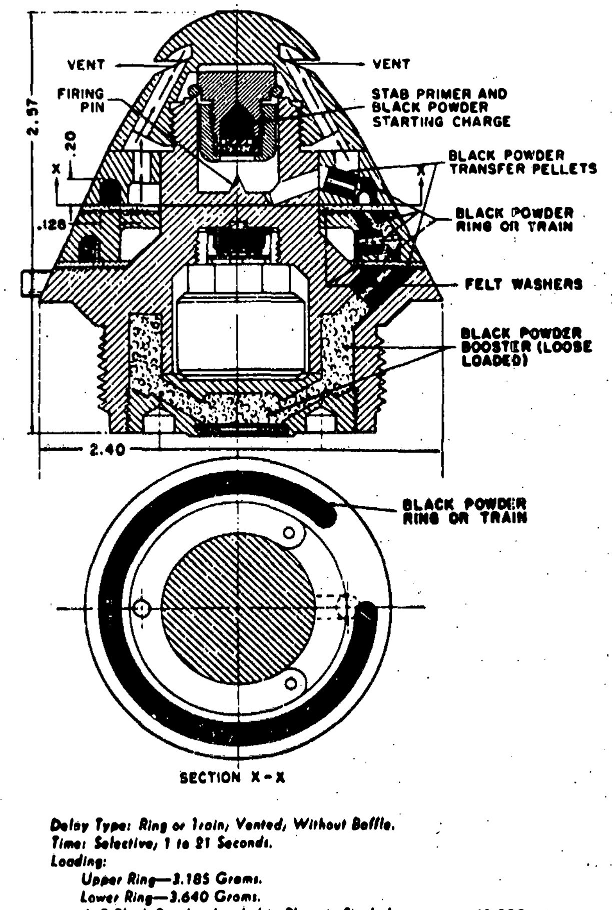
TABLE 5-17
EXTENT OF ANTICIPATORY EFFECT AS A FUNCTION OF BURNING RATE OF VARIOUS BARIUM CHROMATE-BORON

	Average Burning Time, msec		
	95/5	*90/10*	*86/14*
Delay composition alone	464	167	132
Delay composition above terminally pressed 100-mg increment of SI-98	158	124	116
Burning time reduction, msec	306	43	16

SI-98 squibs were empolyed for initiation of columns. Oomposition loaded in M112 fuze housings at 36,000 psi.

SI-98 Composition:

MoO_3—26%
$KClO_4$—21%
Zr—53%



Delay Type: Ring or Train, Vented, Without Baffle.
Time: Selective, 1 to 21 Seconds.
Loading:
Upper Ring—3.185 Grams.
Lower Ring—3.640 Grams.
A-7 Black Powder, Loaded in Place in Single Increment at 68,000 psi.

Figure 5-17. Time Delay Ring or Train, Vented

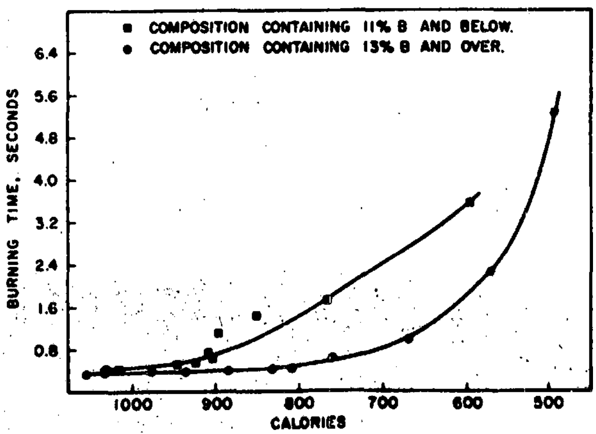


Figure 5-18. Total Heat Evolved Versus Burning Time of Binary Barium Chromate-Boron Compositions Loaded to a Height of 0.79 Inch in M112 Fuze Housing at 36,000 psi

that of a ten-second per inch mix is between 0.125 and 0.156 inch, while for a 12.5-second per inch composition, the failure diameter is between 0.156 and 0.203 inch. As shown in Table 5-21, the effect of column diameter was found to be significant for all 95/5 barium chromate-boron delay systems and for obturated 90/10 barium chromate-boron delays.[48]

5-5.1.3.8 Loading Pressure

Burning rates of delay mixtures will decrease as the consolidation pressure increases. The rather small and systematic changes with loading pressure for barium chromate-boron composition are

TABLE 5-18
EXTENT OF ANTICIPATORY EFFECT AS A FUNCTION OF COLUMN LENGTH 55/35/10 TUNGSTEN-BARIUM CHROMATE-POTASSIUM CHROMATE COMPOSITION*

	*Average Burning Time,**** *msec*	*Burning Time Range, msec*	*Percent Range*	*Δ Burning Time*	*% Column By-passed*	*Length of Column By-passed, in.*
One 1000-mg increment						
Without terminal charge	2348	411	18			
With terminal charge**	1473	462	31	875	37	0.07
Two 1000-mg increments						
Without terminal charge	4291	259	6			
With terminal charge	3404	583	17	887	21	0.09
Three 1000-mg increments						
Without terminal charge	6082	328	5		15	
With terminal charge	5192	1042	20	890		0.09
Four 860-mg increments						
Without terminal charge	6914	337	5			
With terminal charge	6173	990	16	741	11	0.08

*SI-98 squibs were employed for initiation of columns. The compositions was loaded in M112 fuze housings at 36,000 psi.
** SI-98 terminal charges were used.
*** Average burning time values have been reduced by 6 msec in order to take into account the burning time of the terminal charge itself.

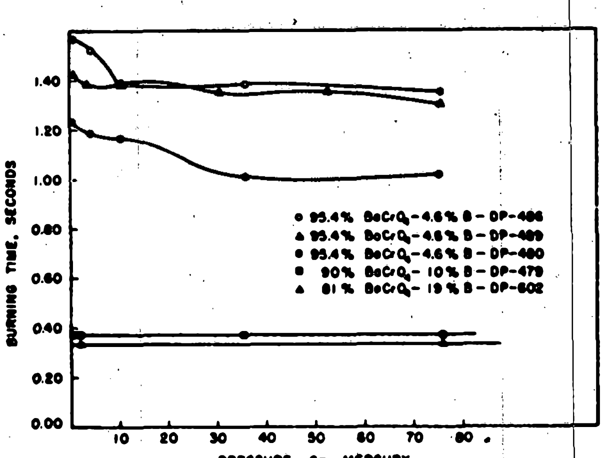


Figure 5-19. Burning Time of M112 Fuze Versus External Pressure

summarized in Table 5-22.[40] These effects might be used to compensate for the differences in burning rate from lot to lot. However, this method has not been used due to the established practice of loading delays at pressures between 30,000 and 40,000 psi in order to withstand the forces to which it is subjected in use. Yielding of the delay element while pressing the delay composition will cause erratic delay times.

5-5.1.3.9 Housing Material

The body into which a delay composition is loaded serves as a heat sink, as metals in general are much better conductors of heat than delay compositions. Delay columns close to their low-temperature failure diameters tend to have larger temperature coefficients as the surrounding wall thickness is increased. For materials well above

TABLE 5-19
EFFECT OF SPECIFIC SURFACE ON BURNING TIME OF TUNGSTEN DELAY COMPOSITIONS

Type of Tungsten Composition		*M10*	*ND 3499*
Fuel Characteristics	Surface Area cm^2/g	1377	709
	Weight Average Diameter, microns	2.3	4.9
Delay Composition, %	Tungsten	40	38.0
	$BaCrO_4$	51.8	52.0
	$KClO_4$	4.8	4.8
	Diatomaceous Earth	3.4	5.2
Burning Time, sec/inch		4.17	21.5

TABLE 5-20
IGNITION POWDERS FOR GASLESS DELAY ELEMENTS

Fuel, %	*Oxidants, %*	*Inert, %*
Zirconium 65	Ferric Oxide 25	Diatomaceous Earth 10
Boron 10	Barium Chromate 90	
Zirconium 33 Titanium 17	Ferric Oxide 50	
Zirconium 51	Ferric Oxide 39	Diatomaceous Earth 10
Boron 30	Lead Peroxide 70	

TABLE 5-21
EFFECT OF FUZE HOUSING MATERIAL AND DIMENSIONS ON BURNING TIME OF BARIUM CHROMATE-BORON COMPOSITIONS

Parameters	*Effect*
1. *Metal Housings*	
a. Aluminum, Brass and Stainless Steel	a. No effect on burning times over test temperatures, internal diameter, wall thickness and for either vented or obturated columns.
	b. No interaction between metal and composition.
2. *Internal Diameter, inch*	
a. *0.250* 95/5 vented vs obturated	a. Results for vented columns significantly different at 95% confidence level.
b. *0.375* 95/5 vented vs obturated	b. Results for obturated columns significantly different at 95% confidence level.
c. *0.250* 90/10 vented vs obturated	c. No significant difference for either column at this diameter.
d. *0.375* 90/10 vented vs obturated	d. Results for obturated column significantly different at 95% confidence level.
3. *Temperature, °C*	
a. — 54, Room Temperature, and 76	a. The effect of temperature was significantly different at the 95% confidence level for all metals, internal diameters, wall thickness and for vented and obturated columns.
4. *Wall Thickness, inch* (0.05, 0.15, 0.30, 0.50, 0.75, and 1.00)	
a. 95/5 vented and obturated columns	a. Results for different wall thickness were significantly different, although no apparent trend was observed.
b. 90/10 vented and obturated columns	b. No significant differences or trends in results due to wall thickness for either type of column.

TABLE 5-22
EFFECT OF LOADING PRESSURE ON BARIUM CHROMATE-BORON COMPOSITIONS

			95/5 $BaCrO_4$-B			
Loading Pressure (10^3 psi)	36	18	9	3.6	1.3	0.5
Mean BR, sec/inch*	1.69	1.60	1.49	1.39	1.29	1.21
Mean BR, sec/gram	0.648	0.655	0.645	0.642	0.646	0.693
% Coefficient of Variation	1.2	0.6	0.7	0.7	0.8	0.8
			90/10 $BaCrO_4$-B			
Mean BR, sec/inch	0.670	0.653	0.619	0.586	0.558	0.544
Mean BR, sec/gram	0.272	0.276	0.280	0.287	0.297	2.309
% Coefficient of Variation	1.5	0.9	1.1	1.6	2.0	1.8

* BR = burning rate.

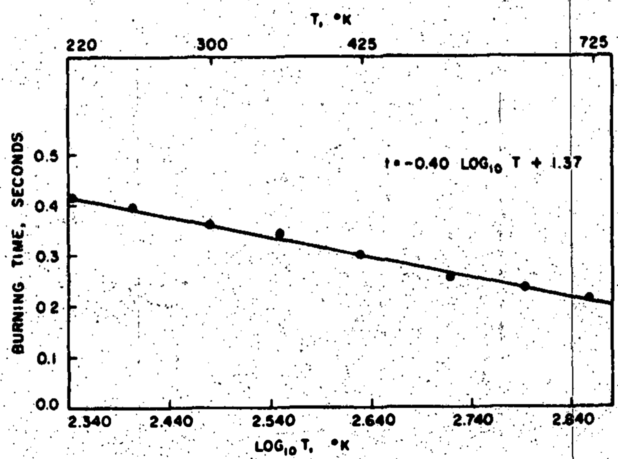


Figure 5-20. Burning Time of M112 Fuze Containing 90% Barium Chromate-10% Boron Composition Versus Logarithm of Absolute Temperature

their failure diameters, the effect of wall thickness becomes less important.[32] As shown in Table 5-21 for the 95/5 barium chromate-boron composition, the wall thickness had a significant effect for both vented and obturated items; however, the differences observed were small and had no apparent trend. No significant difference due to wall thickness was noted for the 90/10 barium chromate-boron compositions.[48]

As also shown in Table 5-21, the material used for the housing did not appreciably affect the burning rate of barium chromate-boron compositions.[48]

Delay compositions have been loaded and consolidated into lead tubing by a swaging technique. The accuracy of delays prepared by the lead-tube method depends on many factors associated with the composition, application, etc. However, it may be said that in some applications it is more accurate and in others less accurate than the conventional method of filling.[49]

5-5.1.3.10 Acceleration

Delay elements are often subjected to very high accelerations while the delay composition is burning, as in skip bombing. If the structure of the material at or behind the reaction front is too weak, the accelerations may cause the hot products to lose contact with the unburned delay composition or a subsequent charge and extinguish the reaction. Quantitative data regarding the resistance of delay compositions to this type of failure are not available. "Slag retention," i.e., the fraction of the weight of the original charge remaining in an open ended delay column after functioning, has been used as a possible qualitative indication of the resistance of a delay element to acceleration forces. Slag retention for some delay compositions is as follows: manganese, > 95%; red lead, 90%-95%; tungsten, > 95%; nickel-zirconium, 80%-90%; boron, 59%-90%.[34]

Introduction of a binder will improve performance under high acceleration conditions; however, binders tend to produce sufficiently large amounts of gaseous products so that the system could no longer be considered gaseless. Mechanical support of the delay column at both ends tends to reduce variation in burning times by minimizing slag flow.

5-5.1.3.11 Storage

The effectiveness of an item of ammunition may depend greatly on accuracy of the delay. Because it is necessary to store ammunition for a long time, it is important to know the effect of storage on the burning times of delay compositions. In general, dry storage for relatively long periods of time results in little change in burning time. For example, barium chromate-boron compositions loaded and stored over a desiccant show little change after time intervals up to two years, as illustrated in Table 5-23. For loose powders stored up to two years in unheated magazines and then loaded, a slight increase in burning time has been observed. Storage under dry conditions prevents further increase in burning time and may reverse the trend as shown in Table 5-24.

When manganese delay mixtures are kept dry, their burning times will not increase more than five percent during eight weeks' storage at +165°F. Some mixtures containing manganese did not change their burning times when stored without sealing at 100 percent relative humidity and +165°F. Other manganese mixtures deteriorate rapidly under the same conditions. This wide variation in storage stability is due to differences in the manganese powder used in preparing them,

TABLE 5-23
EFFECT OF STORAGE ON FUZES LOADED WITH
BARIUM CHROMATE-BORON COMPOSITIONS

	Zero Time			*Stored 19 months*		
Comp., % B	*Mean B. T.,* Sec.*	*Std. Dev.*	*% Coef. Var.*	*Mean B. T.,* Sec.*	*Std. Dev.*	*% Coef. Var.*
10.0	0.514	0.013	2.5	0.515	0.025	4.9
10.0	0.590	0.012	2.0	0.579	0.012	2.2
10.0	0.519	0.015	3.0	0.476	0.010	2.2
10.0	0.574	0.004	0.8	0.522	0.012	2.2
5.0	1.590	0.015	0.9	1.587	0.020	1.3
5.0	1.075	0.016	1.5	1.059	0.015	1.4
5.0	1.294	0.026	2.0	1.264	0.019	1.5
5.0	0.818	0.016	2.0	0.785	0.016	2.0
5.0	1.192	0.036	3.0	1.277	0.016	1.3
5.0	0.986	0.033	3.4	0.955	0.014	1.4
M112 Fuzes loaded at 36,000 psi, stored over desiccant						

* B.T. = burning time.

TABLE 5-24
BURNING TIMES OF FUZES LOADED WITH 93/7 BARIUM
CHROMATE-BORON COMPOSITIONS STORED LOOSE
UNDER VARIOUS CONDITIONS

Initial Conditions		*Storage Conditions*			
Mean B. T., Sec.*	*% Coef. Var.*	*Temp.*	*Time*	*Mean B. T.,* Sec.*	*% Coef. Var.*
		150°C	4 hours	0.707	1.1
			8 hours	0.722	1.0
0.694	2.7	105°C	1 week	0.723	1.8
		50% RH	1 week	0.720	1.5
		Desiccated	1 week	0.685	1.7
0.647	2.3	150°C	4 hours	0.685	2.5
Compositions loaded in M112 Fuze Housings at 36,000 psi.					

* B.T. = burning time.

and, apparently, is associated with the manganese crystallite size and surface oxidation. Protective treatment of the manganese fuel against corrosion —oxidation of surface by dichromation and coating with a thin film of stearic acid—did not improve the dry surveillance properties of manganese delay powders but did improve the wet surveillance characteristics.

For zirconium-nickel delays, four weeks' dry surveillance increases burning times up to 16 percent. Wet surveillance for four weeks results in unreliable performance. Delay compositions of silicon and red lead exhibited increased burning times of up to 10 percent after four weeks' dry surveillance and were unreliable after four weeks' wet surveillance.

In general, results of tests indicate that gasless delays will exhibit changes of up to 15 percent in burning times after four weeks of dry surveillance. Wet surveillance appreciably affects performance of most delay mixtures, in some cases sufficiently to make the mixture unreliable.

5-5.2 HEAT POWDERS[30]

The majority of pyrotechnic heat powders have been developed for thermal battery applications to melt the solid electrolyte and activate the electrochemical system. In general, the heat powder—which generates between 350 and 500 calories per gram—is mixed with inorganic fibers and made into heat paper using conventional paper making techniques. The heat paper can be stamped into required shapes and easily assembled with the other battery components. Other uses include warming of battery electrolytes, melting of soldered joints to activate spring loaded mechanisms, and furnishing heat for thermal delays. Many gasless heat powders and gasless delay compositions can be used interchangeably; however, the electrical conductivity of the products formed during burning is important in the ability of heat powders to satisfactorily perform their function.

The heat output of a heat powder is of prime significance and the burning rate is important only to the extent of its influence on the heat output of the mixture. Other important characteristics include:

a. Heat of reaction. Basically determines the heat output per unit weight of heat powder.

b. Gas evolution. The gases evolved must be controlled because it is possible they will affect the behavior of the heat battery.

c. Burning rate. Basically determines the rate of heat release by the heat mixture powder. (The burning rate of heat paper has been suggested as a means of obtaining a controlled delay time.)

5-6 INITIATORS, FIRST FIRES, AND STARTERS

The initiation of combustion of a pyrotechnic composition requires that a portion of the composition be raised to its ignition temperature. (See also Paragraph 3-3.6.1.) Since some pyrotechnic compositions are relatively difficult to ignite, an explosive train similar to that used in other explosively loaded items is used to produce the ignition stimulus required to initiate the main pyrotechnic composition. Such a train can be considered as divided into three parts. The first part contains a sensitive initiating composition that can be initiated by a relatively small, mechanical, electrical, or chemical stimulus. This initiating composition, on burning, produces sufficient heat to initiate intermediate explosive or pyrotechnic composition(s) in the second part of the explosive train. The output of this second part will initiate the main charge in the third part of the explosive train.[29,31,32] In many cases, a delay train (see Paragraph 5-5.1) can be included in the second part of an explosive train. Emphasis in the following paragraphs will be on initiator, first fire, and starter compositions used in pyrotechnic items.

Work on the development of initiators, first fires and starters for military pyrotechnics has indicated that ignition is a complex phenomenon. Ignition failures of pyrotechnic items emphasized the need for more research and the need for more understanding of the ignition and combustion processes. The available compositions, with descriptions of their applications, are discussed in the paragraphs which follow.

5-6.1 PRIME IGNITION[50]

Prime ignition is the starting of a fire without the use of another fire and includes methods based on friction, percussion, concentration of the sun's rays by mirrors or lenses, and an electric impulse.

Many materials and mixtures of materials have been found which produce heat as a result of chemical reaction and which require relatively little physical effort for initiation. Chemicals, such as white phosphorus and phosphorus-containing compounds, burst into flame on exposure to air. Other materials, including many metals which commonly will not ignite in air, become pyrophoric when finely ground; while other materials are activated by exposure to water or acid, to a spark with a small energy content, or to very slight impact. Still other mixtures require only a small and predictable amount of energy to be initiated. This

last group, which includes matches, is of importance as initiators for ordnance items.

Development of modern matches made fire-making a commonplace act. A safety match head is, essentially, potassium chlorate in a matrix of animal glue. The striking strip is composed of red phosphorus in a similar binder. Use of additives and adjustments in the manufacturing process results in a safety match which ignites easily when rubbed on the striking surface. The friction and contact of potassium chlorate crystals with red phosphorus results in the ignition of the match head which, in turn, causes the ignition of paraffin impregnated in the match splint. A typical match head formula, and that for the striker, are given in Tables 5-25 and 5-26.[50]

TABLE 5-25
COMMERCIAL
SAFETY MATCH COMPOSITION

Ingredient	*Percent**
Animal (Hide) Glue	9-11
Extender (Starch, Dextrin)	2-3
Sulfur (Rosin)	3-5
Potassium Chlorate	45-55
Neutralizer (Zinc Oxide, Calcium Carbonate)	45-55
Infusorial (Diatomaceous) Earth	5-6
Other Siliceous Filler	15-32

*Fractional percentages of a soluble burning rate catalyst, such as potassium dichromate, are added, also soluble dye stuffs. Lead thiosulfate or zinc ferrocyanide can be used if the match head is to be white.

Present "strike-anywhere" (SAW) matches have a small, easily ignitible tip composed of tetraphosphorus trisulfide (phosphorus sesquisulfide) affixed to a larger bulb composed of a rather insensitive modified, safety match head composition. Table 5-27 gives the formulation for two such compositions.[50]

The match mixtures used in munitions are generally much less complicated in composition and manufacture than the commercial match mixtures which require a special striking surface. Compositions which have been widely used in friction primers for artillery are given in Table 5-28. A composition used in the friction primer for an airplane flare contains 14 parts potassium chlorate and 1.6 parts charcoal hardened with 0.3 part dextrin. Ignition is effected by pulling a loop of braided wire coated with red phosphorus and shellac through a pellet of the composition.[51] Modified scratch sensitive mixtures containing some thermite produces very high temperatures and can ignite some smoke mixtures without an intermediate starter.[8]

In addition to matches and other scratch sensitive materials, prime ignition of pyrotechnic munitions, like other munitions, is accomplished with:

a. Percussion (or stab) primer which contains a mixture that is relatively sensitive to impact and friction, or

b. Electrically ignited primer (or squib) in which the heat produced by the flow of electric current in a bridgewire ignites a heat sensitive explosive. For certain applications, especially those involving initiation of high explosives, a bridgewire may be exploded by application of a high current pulse causing direct initiation of some less-sensitive explosives.[29,31,32,52]

Certain chemical reactions have been used for ignition of explosive trains. As has been indicated earlier, some materials burn when exposed to air. An example is white phosphorus. It has been used in bursters for jelled gasoline incendiaries where it serves the dual purpose of igniting the incendiary, and the reigniting jelled gasoline which has been extinguished. Diethyl zinc, or triethyl aluminum, contained in a glass vial, has been used to ignite a match mix in a silent igniter. Some materials, notably the alkali metals, react very vigorously with water, liberating hydrogen which is ignited by the heat of reaction. Bursters filled with sodium have been considered for igniting oil slicks on water.[8] The vigorous chemical reaction resulting from bringing iron powder, potassium permanganate, and sulfuric acid together is another method of prime ignition.

5-6.2 CHARACTERISTICS OF IDEAL IGNITER, FIRST FIRE, AND STARTER COMPOSITIONS

The compositions used to ignite any burning-type pyrotechnic should have the following characteristics:[53]

TABLE 5-26
SAFETY MATCH STRIKER COMPOSITION

Ingredient	*Formula 1,*† %	*Formula 2,*† %	*Formula 3,*† %
Binder	*	20	16
Red Phosphorus	53	50	50
Antimony Sulfide	42	—	—
Charcoal	5	—	—
Carbon Black	—	—	4
Neutralizer (ZnO, $CaCO_3$)	—	—	—5
Sand	—	30	—
Powdered Glass	—	—	25

* In NC laquer, Dextrin, Casein, Animal Glue, plus hardener of U.S. Pat. 2,722,484 129.
† Formulas 1 and 2 are "one-strike" military or firework strikers. Formula 3 is a commercial formula. Antimony sulfide and charcoal act as extenders to the phosphorus. Antimony sulfide also seems to fulfill the role of a neutralizer and preservative for red phosphorus.

TABLE 5-27
SAW ("STRIKE-ANYWHERE") MATCH COMPOSITION

Ingredient	*Formula 1,** %	*Formula 2,** %
Animal Glue	11	12
Extender	4	5
Paraffin	—	2
Potassium Chlorate	32	37
Phosphorus Sesquisulfide (P_4S_3)	10	3
Sulfur	—	6
Rosin	4	6
Dammar Gum	—	3
Infusorial Earth	—	3
Powdered Glass and Other Filler	33	21½
Potassium Dichromate	—	1½
Zinc Oxide	6	1

*Formula 1 represents the tip formula which ignites on any hard surface. Formula 2 is the match composition's base, loaded with combustibles for strong billowing flame but of low friction sensitivity.

a. Be ignited by the primer, fuze, or match employed in the munition.

b. Ignite the main pyrotechnic composition.

c. Be sufficiently insensitive for safe handling in manufacturing and loading operations.

d. Be resistant to the effect of moisture.

The specific nature of the ignition composition is primarily determined by the particular ignition problem since it involves the nature of the filling to be ignited and the method by which the ignition composition is ignited. The wide variety of fillings used in burning-type munitions makes it impossible

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TABLE 5-28
FRICTION PRIMER COMPOSITIONS

Ingredient	Parts by Weight	
Potassium Chlorate	56.2	44.6
Antimony Sulfide	24.6	44.6
Sulfur	9.0	3.6
Meal Powder		3.6
Ground Glass	10.2	3.6

to develop one composition for all purposes. A composition producing a slag and a high temperature would be desirable for ignition of a thermite-type incendiary or most illuminating compositions, but would be unsatisfactory for ignition of a colored smoke since the high temperature would cause flaming of the dye.

Requirements for ignition compositions, therefore, must be varied depending on their use. Ignition mixtures can be classified as slag-producing or gas-producing mixtures. As some compositions produce both slag and gas, the type of filling to be ignited appears to be the most practical basis for differentiation of the various compositions. Ignition compositions may be classified as those:

a. For munitions containing thermite-type fillings or illuminating compositions, the reaction should be very hot yet evolve little gas.

b. For munitions containing HC smoke fillings, the reaction should be hot and preferably produce some slag; some evolution of gas is acceptable.

c. For munitions containing colored smoke mixtures and toxic smoke mixtures, the reaction product may vary from gaseous slag to highly gaseous with no slag.

Ignition compositions which are used as rocket motor igniters are usually ignited by the output of a black powder which was commonly used for this purpose, has been replaced by igniter compositions composed of a powdered metal and inorganic oxidizer.

5-6.3 TYPICAL COMPOSITIONS

The compositions of typical igniter, first fire, and starter mixtures are given in Table 5-29.

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TABLE 5-29
SOME FIRST FIRE, STARTER, AND IGNITER COMPOSITIONS

	Composition (Percent by weight)					
Aluminum						13
Boron				10		
Charcoal						4
Magnesium					25	
Silicon	20	25				26
Titanium		25				
Zirconium			20			
Zirconium Hydride	15					
Barium Chromate						
Barium Nitrate	50			90	75	
Iron Oxide (Fe_3O_4)		25				
Iron Oxide (Fe_2O_3)		25				
Iron Oxide (Scale)						22
Lead Oxide (PbO_2)			80			
Lead Oxide (Pb_3O_4)						35
Potassium Nitrate						
Tetranitracarbizole	5					
Laminac Binder	5*	**	**	**	**	**

* Laminac binder: Laminac 99%; Lupersol 1%.

** Most of these compositions can be used as a loose powder mixture or with binders such as celluloid, nitrocellulose or NC lacquer.

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CHAPTER 6

PRODUCTION OF LIGHT

6-1 HISTORICAL SUMMARY

Military pyrotechnic items used for illumination and signaling by the military share a common origin with the spectacular white and colored flames produced by fireworks. Tracing the development of these compositions is relatively easy since there was little progress made in the development of flame producing compositions until the introduction of potassium chlorate pyrotechnic mixtures near the end of the 18th century.[1]

6-1.1 CONSOLIDATED ILLUMINANTS

6-1.1.1 Flares and Signals

Modern fireworks, with a few exceptions, can be divided into two types, those designed to produce force and sparks, and those producing a flame.[1,2] Early efforts were directed toward the development of spark and force producing compositions. At that time, there was no known way of imparting color to a flame. As a result, there was little difference to the eye between a flame produced by a pyrotechnic mixture and one resulting from the burning of pitch, petroleum, or resinous wood. Sparks could be varied in form and brightness, although not in color, so that spark compositions became, and remained for centuries, the main consideration of the fireworks maker.

The few flame compositions available in the 17th century usually included a flammable liquid in order to ensure combustion of the rest of the mixture consisting of gunpowder, antimony sulfide, and arsenic sulfide. Appier[1,2] was far in advance of his time when he suggested the use of acetate of copper to give a green tint to a flame. By the early part of the 19th century, a pyrotechnist, Claude-Fortuné Ruggieri,[3,4,5] suggested the use of metal salts and ammonium chloride in the production of a colored flame.

The modern era in pyrotechnics began with the introduction of potassium chlorate which was first prepared in 1786 and first mentioned as an ingredient in a pyrotechnic composition in 1823.[6] By 1830 several formulas containing potassium chlorate had been developed for firework display, military signaling and signaling at sea. While most colors could be produced in a more or less satisfactory manner by 1850, it was several years later before a satisfactory blue flame was produced. This was accomplished by adding copper salts to compositions containing potassium chlorate. The color was enriched by the use of calomel, Hg_2Cl_2. During this period colored flames produced by adding color-emitting salts to potassium chlorate and sulfur compositions were found to be very satisfactory. In spite of their good color quality, these compositions were abandoned because of their sensitivity to impact and friction. Sulfur was replaced first by powdered shellac and later by other gums and resins.

Magnesium was first produced on a commercial scale in 1860 and was used by European pyrotechnicians several years later. In the United States, possibly because of its cost, magnesium was not used in military pyrotechnic mixtures until around 1926. Aluminum was not used appreciably in pyrotechnic compositions until near the end of the 19th century when it became commercially available.

Illuminating compositions for military applications were, basically, the same as those used in firework displays over two hundred years earlier. A primitive type of light producing item—whose composition consisted of saltpeter, sulfur, resin, and linseed oil—was included in British military stores until at least 1870. Most important of the few inventions in military pyrotechnics during the latter part of the 19th century was the parachute light which appears to have originated about 1820 in Denmark much in advance of its widespread use in the World Wars of the 20th century. Another invention, the Very Pistol which was patented in 1878, originated as a civil signaling device. Ini-

tially, the pistol had a one-inch bore; this was later increased to one and one-half inches during World War I. Improved illuminating and signaling devices were developed in the 1914-1918 period because they were required in the trench warfare of World War I to a much greater extent than in prior wars. The growing importance of air warfare opened a whole new field for the use of illuminants and signals. Simulators and decoys were developed for the purpose of misleading enemy observers.

Most of the illuminating and signaling devices produced in the period between World Wars were developed by empirical methods. The limited amount of work performed in this period necessitated a hurried attempt to put the pyrotechnic field on a scientific basis at the start of World War II. This attempt was hampered by the necessity of producing items for immediate use on the battlefield. Most of the research and development continued to rely upon empiricism. However, a limited amount of basic and applied research, much of it directed toward the development of better light producing compositions, was started at several of the Government installations and continued after the war. Results of the work done after the war were extremely rewarding. At the end of World War II some opinion was expressed that little improvement could be made in flare and photoflash compositions.[7] Contrary to this opinion, major improvements were made, some of them in time to be of great service in the Korean Conflict.[8]

Current research and development effort is being directed toward the development of advanced flare compositions, for both illuminating and signaling purposes, to function at altitudes where little or no atmospheric oxygen is available.

6-1.1.2 Tracers

Before the invention of gunpowder and the use of bullets, there was no need for tracers. The projectiles used, namely spears and arrows, were large in size, and traveled at a low velocity, so that their line of flight could be readily followed. Arrows tipped with burning grass might be considered the first tracers. Though the prime reason for using these burning arrows was to start fires, the course of the arrow could be followed at night.

The range of the crude guns introduced after the invention of gunpowder was so short that the point of impact of the projectile could be noted by the eye. However, this was no longer possible after the introduction of weapons which fired small-caliber, high-velocity bullets over ranges of more than a thousand yards. During World War I, the need for tracers was intensified by the wide use of machine guns. The need for tracers became acute, coincident with the enormous expenditure of ammunition by infantry and air service. At long range, in the air and on the ground, it was almost impossible to estimate range and correct aim by observing the point of impact of bullets which did not incorporate tracers.

During World War I, the air services of both the Allied and Central Powers urgently demanded an efficient, accurate tracer bullet and, as the result, tracer ammunition was soon developed by all of the belligerents. A German tracer composition —containing a mixture of magnesium, strontium nitrate, calcium hydroxide and rosin—was not very satisfactory because it was difficult to ignite and produced a very dim and indistinct trace. The French tried several tracer mixtures which contained a small amount of linseed oil as a binder. These tracers were quite brilliant and dependable but were unstable in storage and became practically useless soon after manufacture. As a result, French tracers were made immediately behind the lines so that the ammunition could be placed in the hands of the troops as promptly as possible. If the ammunition could not be used within two or three weeks, it was scrapped and replaced.

After the United States entered the War, a program of developing better tracer ammunition for the American Expeditionary Forces was activated. The result of this work was the development of M1917 tracer ammunition, which consisted of a jacket of cupronickel surrounding a container of gilding metal and a lead shot. The tracer composition was a mixture of barium peroxide and magnesium in grain alcohol, which was dried and pressed into the container at 48,000 pounds per square inch. This tracer was quite satisfactory and produced a trace—which was not especially brilliant—for about 500 yards. Another tracer

was developed in cooperation with the British, using a mixture of barium nitrate, barium peroxide, and magnesium loaded in a hollow brass bullet. An igniter mix of barium peroxide and magnesium was required with this tracer mixture.

The using services were not satisfied with the status of tracer ammunition at the end of the War, and again studies directed toward the production of a better tracer bullet were resumed. Many mixtures were tried during this period and it was found that calomel would increase the brilliance and luminosity of the trace produced; this resulted in the introduction of the M1923 tracer bullet, caliber .30, and the design of an M1924 prototype. During this period, tracers were developed for caliber .50 and also for caliber .45 weapons; these were used primarily as red, green, and white signal rounds. It is also interesting to note that the M1923 tracer was evaluated as a small arms incendiary bullet and found to be superior to the then-available small arms incendiary ammunition; for some time thereafter this tracer also served as a small arms incendiary. By December 1926, military requirements brought about standardization of the red tracer as the only one approved for general military use. The designation was "Bullet, Tracer, Caliber .30, M1." The tracer composition contained strontium peroxide made by the dry process and a higher-density calomel.

The igniter composition contained barium peroxide and fine magnesium. Tracer M1 was also loaded with a subigniter consisting of three parts igniter and one part tracer composition to insure ignition of the tracer composition. These changes resulted in an increased length of trace to 1300 yards for caliber .30 tracers, and to 2200 yards for caliber .50 tracers. Research and development concerned with small arms ammunition continued at a very limited rate resulting in changes such as the development of a gilding metal bullet jacket to replace the cupronickel jacket. The bullet design of the caliber .30 M1 tracer was standardized in 1929, based upon the M1924 prototype round; however, the pyrotechnic compositions were changed significantly during the period between World War I and 1929. For example, many strontium compounds such as strontium peroxide, strontium oxalate, and strontium nitrate were investigated as a means of improving color of the flame and buring. During this period, calcium resinate was introduced as an improved composition binder. By 1929, there was concern as to the effects of incorporating mercury compounds such as calomel in tracer bullets because, under certain conditions, it was observed that the jackets split in storage, probably due to the liberation of the mercury from the calomel. Investigation proved that the cracking of the jacket was due to the presence of free mercury, and elimination of tracer compositions followed.

In addition to this work, a limited amount of research and development effort directed toward the development of red tracer compositions for ammunition larger than caliber .50 was initiated. During this same period, the Navy had developed and adopted satisfactory compositions for red, white, green, and orange tracers.

About 1934, study of test records showed that Army tracers became unsatisfactory after five years' storage. The tracer composition had been wet-processed to obtain good storage stability; i.e., the calcium resinate was dissolved in carbon tetrachloride, mixed to a paste with the other ingredients, baked dry, and pulverized to a powder to render all ingredients moisture-repellent. Poor storage stability was apparently due, not to the tracer composition, but rather to the dry-blended barium peroxide-magnesium-red lead igniter composition. Red lead, although aiding bonding and identification of the igniter composition, was found to be chemically incompatible with barium peroxide and, therefore, was removed from the formula. The magnesium was pre-treated with water to form a protective oxide coating and one percent zinc stearate was added as a water repellent. This igniter blend proved to be more stable under high-humidity testing and was adopted for use in 1937.

During the period from 1935 to 1941, development work on delay action and dim igniters for small arms tracers was active.[9,10] Two compositions were developed which were standardized. These compositions form the basis for all delay action and dim igniters used in small arms ammunition. The basic composition is designated I-136 Delay Action and is composed of 90 percent strontium peroxide and 10 percent calcium resi-

order to increase the number of photographs obtainable on a mission. It contained about seven pounds of flash powder in a cylindrical paperboard case. Later it was placed in a streamlined steel outer case to improve its operational characteristics. Development of the M46 Photoflash Bomb was started just before the United States entered World War II. This bomb contained up to 25 pounds of photoflash mixture in a streamlined metal case and was widely used in World War II for photography from intermediate altitudes.

In an attempt to increase the intensity of the light from pyrotechnics, scientists under National Defense Research Committee auspices at Wesleyan University and at the California Institute of Technology conducted a more fundamental study of photoflash powder. Both groups reached the conclusion that no real improvement in flash output could be gained by changing the standard magnesium-aluminum-potassium perchlorate mixture then in use. Consideration was then given to possible methods of obtaining a more efficient distribution of the light from the flash. Further study, however, indicated that a larger bomb was an easier way to obtain higher levels of illumination. Because of shortages of aluminum and magnesium powders at the start of World War II, a mixture using a magnesium-aluminum alloy as a fuel instead of a mixture of magnesium and aluminum, known as Type II, Class A, photoflash powder was developed. Later, barium nitrate was adopted as the oxidizer. This mixture was known as Type II, Class B, photoflash powder. Later, a new standard photoflash powder, Type III, Class A, consisting of 40 percent aluminum, 30 percent barium nitrate, and 30 percent potassium perchlorate was adopted.[18] It was found that the latter mixture, when confined in a heavy-walled casing, would produce more light output from a smaller and safer photoflash bomb. These results led to the cancellation of further work on thin-walled photoflash bombs for high altitude, night aerial photography, and led to the development of the safer heavy-walled bombs. These bombs were in production in late 1951 and were used in the Korean Conflict in 1952. While much safer than the M46, this type of bomb still did not meet the requirement that it should be no more sensitive to projectile fragments and bullet impact than a general purpose bomb.

Work on photoflash compositions continued with considerable emphasis directed toward the development of flash mixtures containing calcium, which were more effective at higher altitudes than other photoflash mixtures.

6-1.2.1.1.2 Dust Type[14]

The need for night illuminant safer than the standard flash powder bomb (which was easily detonated by bullet impact) led to a requirement for a less-sensitive powder composition. This approach was considered to be preferable to armoring the bomb. By 1943, British reports of the development of a safe metal dust bomb, using either aluminum or magnesium powder detonated by a tetryl burster, had been received. Initial tests made in this country of the metal dust type were not encouraging. It was found that the "safe" powder produced only about 20 percent as much light as the standard photoflash bomb. Further work resulted in the T8 bomb, which was a complete failure. Instead of dispersing as a dust to explode in a short bright flash, the milled magnesium powder used in the bomb apparently compacted into large adhering masses which burned progressively.

The T8E1 bomb, containing 70 pounds of flake aluminum and weighing over 200 pounds, reached a peak intensity of one billion candlepower in about 12 milliseconds. This was little more than the peak candlepower of the 50-pound M46 bomb. A ring-shaped flash with a characteristic nonluminous core was produced, presumably caused by gaseous decomposition of the high explosive burster. The same dark center was also noted in the British dust bombs, Mark III and Mark IV. By the end of the War, small scale tests of a variety of metal dusts, bursters, and casings showed that a conical burster eliminated the dark core.

Continuing research on metal dust bombs showed that a satisfactory bomb was unattainable with magnesium dust. The smaller the burster, in proportion to weight of dust, the greater the efficiency in terms of candlepower-seconds per gram, but the slower the flash. No satisfactory point of

compromise could be found. The use of atomized magnesium-aluminum alloy was then suggested because of its nonhygroscopic nature. It provided twice the peak candlepower of magnesium dust accompanied by relatively little change in total light output.

A separate development project was started in 1948 and led to the standardization of the M122 dust bomb in 1952.[15] The M122 was eight inches in diameter by 54 inches in length, with a total weight of 110 pounds. The bomb achieved a peak of 0.82 billion candlepower, although the average of several tests was about 0.70, and in the best 40 millisecond period it produced 31.9 million candlepower-seconds. It was slow to peak, requiring about 42 milliseconds. The flash was so long in duration that on one occasion two photographs were taken with a single camera using the light of a single bomb. Under ideal conditions of clear atmosphere and high reflectance terrain, it was possible to obtain usable photographs at altitudes of 16,000 to 20,000 feet. Good photos under normal conditions were possible at altitudes of 5000 to 12,00 feet. The bomb was stable from an airspeed of 185 to 400 miles per hour. The RB-26 aircraft carried a load of ten M122 bombs; the RB-45C carried twenty-five; and the RB-50 carried fifty-two. Procurement was initiated too late for use in the Korean action.

6-1.2.1.1.3 Segregated Oxidant Type

In 1950, the development of a segregated oxidant type photoflash bomb was begun in an attempt to obtain both the safety from impact initiation associated with the dust type bomb and the high peak light intensity associated with the photoflash powder type bomb. In addition, this type bomb—in which the burster, oxidant, and metal dust are loaded separately in coaxial cylinders—also should be relatively insensitive to altitude as compared to the dust which depend entirely on atmospheric oxygen. Considerable effort was directed toward the development of a bomb of this type; however, the results obtained did not prove to be markedly superior to those obtained with the newer nonsegregated types. As a result, the segregated oxidant photoflash bomb was not developed into a standardized item.

6-1.1.2.2 Photoflash Cartridges[16]

While most of the night aerial photographs during the early phases of World War II were obtained at relatively high altitudes, the need for low level night aerial photographs during the latter phases of the war was anticipated. Therefore, development of suitable photoflash mixtures, as well as cartridges and ejectors for this purpose, was started but the work progressed slowly because of low priority.

In 1943 when the need became acute, the United States' designs were not complete and a photoflash cartridge designed and developed by the British was used. This cartridge was based on the case used for the Very parachute flare. By 1945, the first low altitude photoflash cartridge developed in the United States was based on a standard signal flare case and contained about five ounces of Type II, Class B flash powder. Its light output characteristics were poor and, hence, it was not standardized or used during World War II.

The first United States standardized photoflash cartridge was developed by 1949. It contained the then new Type III photoflash powder and could be used to obtain satisfactory aerial photographs up to an altitude of 4000 feet. These cartridges were used extensively in the Korean Conflict for low altitude night reconnaissance photography. As the tactical situation in Korea often required night photographs at higher altitudes, the M46 bomb was also widely used. However, due to the greater weight of the M46 bomb, fewer units could be carried, resulting in a demand for smaller units having adequate candlepower. This requirement had been anticipated and tests using the Type III, 30/40/30 formula (potassium perchlorate 30%, aluminum 40%, and barium nitrate 30%) had been made as early as 1947, using charges ranging in size from 1.7 to 7 pounds. The 1.7-pound charge was found to be entirely adequate up to 8000 feet and was loaded as the M123 cartridge with an obturated delay fuze of two, four, or six seconds. Work on photoflash cartridges continued after the Korean Conflict.

In 1951 an atempt was made to obtain an increased light output together with safe characteristics for use in photoflash cartridges. A high

metal content mixture (70 percent aluminum and 30 percent potassium perchlorate) was used with massive bursters of RDX. This mixture gave twice the total light of the Type III 30/40/30 formula and was relatively insensitive to both friction and flame initiation. Since that time, a limited amount of work has been continued on photoflash cartridges and associated high rate ejection systems for night aerial photography and other purposes.

6-1.2.2 Spotting Charges

For many years, the flash and smoke produced by the functioning of a small explosive charge, usually black powder, was used as an aid in spotting the point of impact of practice ammunition. Occasionally, these charges were also used in connection with certain items of service ammunition.

During and after World War II, the development of large caliber weapons for use in tanks created a need for simple and reliable target acquisition for these weapons. One of the more satisfactory systems developed employed a subcaliber spotting rifle aligned with the major weapon. This rifle fired a projectile having a trajectory closely matching, in the critical range, that of the major weapon so the location of the flash and smoke produced by the pyrotechnic charge in the subcaliber round indicated where the major round would hit.

High precision tracking data is necessary in the development of intermediate- and long-range missile systems. To obtain this data, brilliant light flashes must be produced of sufficient intensity to be recorded by a tracking camera and also be of a short enough duration to provide accurate position information. Early sources of light used for this purpose were of the gas discharge type. To obtain sufficient light intensity without the weight penalty associated with electronic flash systems, pyrotechnic light sources were developed for this purpose. While the first pyrotechnic system developed, the Daisy Photoflash Cartridge, was a satisfactory light source for a tracking aid, it created other problems, the most serious of which was the production of metal fragments and attenuation of radio signals, which resulted from the functioning of the flash signal.

In addition to minimizing these problems, further development resulted in a series of flash signals of differing intensities which allowed more flexibility in programing of flashes along the trajectory of the missile. Flash signals also have been developed to evaluate the functioning of the missile warhead frequency system.

Further information and references on nonconsolidated illuminants may be found in comprehensive reports available.[17,18,19]

6-2 THEORY OF LIGHT AND COLOR

6-2.1 BEHAVIOR OF LIGHT

In a strict physical sense, light is that electromagnetic radiation which affects the eye and produces vision. The wavelength range of visible radiation extends from approximately 3800Å to 7000Å; the angstrom unit, Å, is equal to 10^{-8} centimeters. Other units used for indicating the wavelength of electromagnetic radiation include the micron, μ, which is equal to 10^4 angstrom units. In a less strict sense, the term light is also applied to electromagnetic radiation whose wavelengths are longer (infrared) or shorter (ultraviolet) than those for visible light.

All forms of electromagnetic radiation, including light, are absorbed and emitted as integral numbers of energy quanta and are transmitted by particles known as photons. The amount of energy, E, associated with each photon is:

$$E = h\nu \qquad (6\text{-}1)$$

where ν is the frequency of the radiation, and h is Planck's constant. This equation is often expressed in other ways, such as:

$$E = \frac{hc}{\lambda} = hc\tilde{\nu} \qquad (6\text{-}2)$$

where c is the velocity of light in centimeters per second; λ is the wavelength in centimeters; $\tilde{\nu}$ is the wave number, the reciprocal of the wavelength in centimeters; and h is Planck's constant.

All electromagnetic radiations, including light, have both particle and wave properties. This dualistic nature is also applicable to matter. According to the deBroglie equation, the wavelength associated with a particle of mass m moving at a velocity v is given by:

$$\lambda = \frac{h}{mv} \qquad (6\text{-}3)$$

Many of the effects of light may be simply explained by assuming that light, in a uniform medium, will travel in straight lines at measurable velocity. This assumption, which is the basis for geometric optics, is very nearly true in most cases of interest in pyrotechnics. The direction, or path of light, is often represented by a straight line called a ray. Other effects, which cannot be explained by geometric optics, must be discussed in terms of the wave nature of light, while still others must be explained in terms of the particular nature of light.

A knowledge of the properties of light is important in pyrotechnics due to the need for measurements and instrumentation required for evaluation, and to carry out the necessary research aimed at improving light and color sources. Some of these properties include reflection, transmission, absorption, refraction, and the optical characteristics associated with mirrors and lenses. These subjects will not be discussed in detail as standard physics texts cover them and may be consulted when required.[20] One of the most important characteristics associated with the electromagnetic spectrum of radiation is spectral distribution; analysis of this distribution provides an excellent tool for determining the emitting species in flames and other light sources. For this reason, several of the subsequent paragraphs are devoted to this area.

6-2.2 SPECTRAL DISTRIBUTION

If a narrow beam of white light is passed through a prism, each wavelength is deviated in direction by a different amount and the light beam is spread out into an array of colors. The array of colors is called the visible spectrum, and extends from about 0.4-micron to about 0.7-micron. This visible portion of the spectrum represents a very small fraction of the electromagnetic radiation commonly emitted by radiation sources, and lies between the longer wavelength (infrared) and the shorter wavelength (ultraviolet) portions of the electromagnetic radiation spectrum to which the eye is insensitive.

Spectra of two general types are observed, emission spectra and absorption spectra. Emission spectra are produced by light which is emitted from luminous and incandescent bodies and consist, in the optical region, of colored lines, colored bands, and colored regions on a dark background. Absorption spectra are produced by white light which has been passed through gases, liquids, or other light-absorbing materials on a brightly colored background. Both types of spectra can be observed in wavelength regions outside the visible by special techniques.

Depending on the appearance of the spectra produced in a given wavelength interval, both emission and absorption spectra can be further classified as discrete or continuous spectra. The spectral distribution of the light produced by pyrotechnic light sources for both illumination and signaling is important; therefore emphasis in the following paragraphs will be on emission spectra.

6-2.2.1 Discrete Spectra

Luminous gases and vapors under moderate or low pressures yield emission spectra which consist of definitely placed bright lines or closely placed groups of bright lines called bands. The energy, E, associated with a quantum of light having the same frequency, ν—i.e., a spectral line—is:

$$E = h\nu = E_2 - E_1 \tag{6-4}$$

where h is Planck's constant. This energy is the difference between two quantized energy levels in the atom or molecule, designated above as E_1 and E_2, so that the wavelengths of the spectral lines are characteristic of the radiating source. The number of lines and their relative intensities in an emission spectra also depend on the method of excitation.

A line observed in an emission spectrum results from the transition of the atom or molecule from a higher, E_2, to lower, E_1, energy level;[21] i.e., the transfer of quanta of energy is evolved. If the line is observed in an aborption spectrum, the atom or molecule is raised from a lower to higher quantized energy level by the absorption of a light quantum of the proper frequency.

6-2.2.1.1 Line Spectra[22]

Line spectra—consisting of a series of sharp, brightly colored lines on a dark background—are produced by single or chemically uncombined

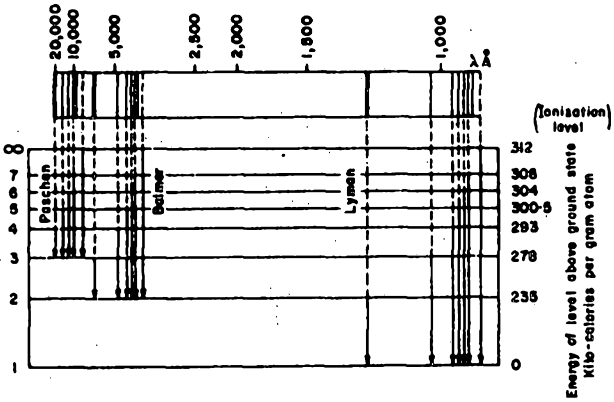

Figure 6-1. Emission Spectrum and Energy Levels of Hydrogen Atom

atoms and, therefore, are often called atomic spectra to distinguish them from the band spectra characteristic of molecules (Paragraph 6-2.2.1.2). The complexity of the line spectra produced by emission depends on the particular atom involved and the method of excitation. Normally, more lines appear in a spark spectrum than in an arc spectrum and both exhibit more lines than a spectrum produced by thermal excitation in a flame.

The term "line spectra" can also be considered a collective term including both atomic and ionic spectra. In this context, atomic spectra are produced only by neutral atoms while ionic spectra refers to spectra produced by ionized atoms. Less energy is required to excite an atomic line than is required to ionize an atom and excite an ionic line. In general, therefore, only atomic lines are found in the spectra excited by arcs and flames. Lines due to ionized atoms are found in spark-excited spectra where excitation is due to high velocity electrons and the energy is sufficient to excite spectra corresponding to large differences in energy.

Because the energy levels in an atom are related to the configuration of the extra-nuclear electrons, the simplest line spectra are produced by atomic hydrogen (note that the spectra for ionized helium will be similar) where the observed spectra (Figure 6-1) can be represented by:

$$\tilde{\nu} = R\left(\frac{1}{k_1^2} - \frac{1}{k_1^2}\right) \qquad (6\text{-}5)$$

where $\tilde{\nu}$ is the wave number, the reciprocal of the wavelength in centimeters; R is the Rydberg constant; and k_1 and k_2 are integers. The Lyman series found in the ultraviolet, and for which $k_1 = 1$ and $k_2 = 2, 3, 4, ---$, is caused by transitions from excited atomic states to the ground state or lowest atomic energy state, as is also illustrated in Figure 6-1. The Balmer series found in the visible spectra for which $k_1 = 2$ and $k_2 = 3, 4, 5, ---$, is caused by transitions from excited atomic states to the first excited state. Other series—including the Paschen series, Brackett series, and Pfund series—are found in the infrared. The spectral lines for materials of higher atomic number rapidly become so complex that they cannot be represented by a single simple equation.

6-2.2.1.2 Band Spectra[23]

The emission spectra in the visible or ultraviolet region, due to molecules, consist of a relatively large number of regularly arranged, but complicated, groups of lines called bands. These line sequences are called bands because they appear as structureless bands in low dispersion spectrographs. Each band spectrum shows, in general, a threefold structure. It consists of a number of similar but separated groups of bands making up the band systems. Each band system is made up of a number of bands, sometimes arranged in sequence, consisting of a number of regularly arranged lines.

This threefold structure is due to the partitioning of the total internal energy of the molecule into three parts resulting from: the electron configuration, the vibration of the atoms in the molecule with respect to each other, and the rotation of the molecule. Therefore, the location of the band system in the visible or ultraviolet region of the spectrum is determined by the magnitude of the energy changes associated with these transitions. All bands of a band system are associated with the change in electron configuration. The position of band in a band system is associated with a change in vibrational energy; changes in the rotational energy determine the location of the different lines.

Changes in energy of a molecule due to a change in rotational energy are an order of magnitude smaller than those due to vibrational changes which, in turn, are an order of magnitude smaller than the energy changes due to a

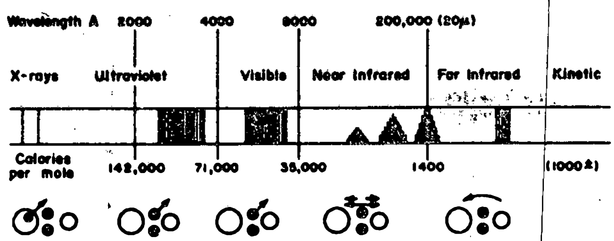

Figure 6-2. Various Types of Spectra and Corresponding Electronic, Vibrational and Rotational Motion

change in electronic configuration of the molecule (Figure 6-2). The relatively small amounts of energy corresponding to emission or absorption in the far infrared and microwave regions are due to changes in rotational energy of the molecule. The spectrum associated with these changes is called the rotation spectrum. The energy changes corresponding to the spectrum found in the near infrared are associated with changes in vibrational energy. The superimposition of the effects due to rotation, on those due to changes in vibrational level, result in the more complex vibration-rotation spectrum. As already indicated, the band system found in the visible and ultraviolet is due to the superimposition of energy changes due to changes in electron and configuration in vibration and rotation.

6-2.2.2 Continuous Spectra[21,24,25]

A continuous emission spectrum in the visible region is a continuous brightly colored band extending from color to color. Incandescent solids, liquids, and gases, under high pressures, produce a more or less continuous spectrum which may extend without interruption from the extreme ultraviolet through the extreme infrared. The energy in any range, λ to $(\lambda + d\lambda)$, of wavelengths of a continuous spectrum is a continuous function of the wavelength so that the radiation is characterized by a continuum of wavelengths.

While continuous spectra are generally produced by incandescent solids, liquids, and gases; regions of continuous emission or absorption may result in gases at low pressure when at least one of the energy states involved in the transition is unquantized, possessing free kinetic energy. These continua, therefore, correspond to processes such as ionization, recombination and association.[25,26]

6-2.3 RADIATION SOURCES

Radiation sources can be classified in terms of the spectral distributions of their radiation and in terms of the manner in which this radiation is excited. Continuous radiation is generally produced by hot solids (Paragraph 6-2.2.2). Although light produced by certain lasers is very nearly monochromatic, there is no source of strictly monochromatic radiation. A narrow range of wavelengths can be obtained by isolating, with a monochromator or filters, one of the bright lines produced in emission by certain elements. A wider range of wavelengths (however manifest in the visible spectrum to give the sensation of a color) can be isolated by similar methods from sources producing band or continuous spectra.[27]

6-2.3.1 Thermal Radiation Sources

Many radiation sources are based, at least in part, on the emission from a material heated to a high temperature. The radiation produced is continuous in nature, resembling that of a blackbody.

6-2.3.1.1 Blackbody

A "blackbody" is an idealized body which will absorb all the radiant energy falling upon it. A blackbody can be approximated experimentally by an enclosure having a very small opening in one wall through which radiation may enter or leave. According to the Stefan-Boltzmann Law, the total radiation E emitted by a blackbody at an absolute temperature T is:

$$E = \sigma T^4 \qquad (6\text{-}6)$$

where σ is a constant equal to 7.56×10^{-5} erg cm^{-3} deg^{-4}. The intensity of radiation from a blackbody at a given temperature varies with the wavelength according to Planck's Equation:

$$E_\lambda = \frac{2\pi c^2 h}{\lambda^5 (e^{hc/k\lambda T} - 1)} \qquad (6\text{-}7)$$

where E_λ is the radiance of wavelength λ, c is the velocity of light, k is Boltzmann's constant, and h is Planck's constant. This equation, which is plotted at various constant temperatures in Figure 6-3, gives calculated values which are in extremely good agreement with the intensity values deter-

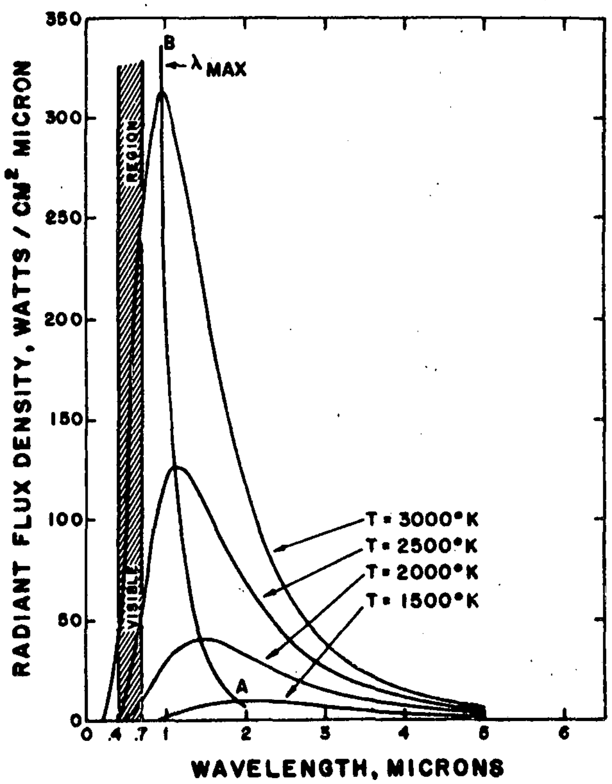

Figure 6-3. Planck's Law: Radiance as a Function of Wavelength for Various Temperatures

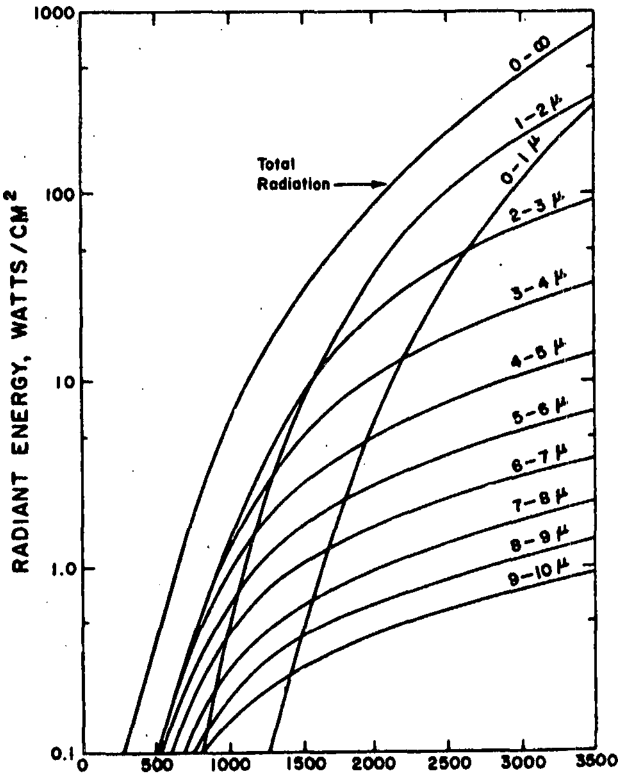

Figure 6-4. Radiant Energy in Different Wavelength Bands as a Function of Temperature

mined experimentally. The function has a single-valued maximum, for each temperature, which varies with temperature along curve AB in Figure 6-3. The wavelength of the maximum is given by the equation:

$$\lambda_{max} = \frac{2897}{T} \tag{6-8}$$

and the radiance at λ_{max} is given by:

$$E_{\lambda_{max}} = 1.178 \times 10^{-7} T^5 \tag{6-9}$$

As shown in Figure 6-4, the amount of energy radiated in any given wavelength region by a constant temperature blackbody radiator increases continuously but at different rates relative to the increase in the total amount of radiation, with temperature. Therefore, as shown in Figure 6-5, the efficiency of conversion of thermal energy into radiation in a particular band varies with the temperature and exhibits a maximum. As the wavelength of the band increases, the temperature for maximum efficiency decreases as does the value for the maximum efficiency.[28]

6-2.3.1.2 Graybody

A graybody, or nonselective radiator, radiates at every wavelength an amount of energy bearing a constant ratio to the amount radiated by a blackbody at the same absolute temperature. This ratio is called the emissivity and is less than one for all solid radiators, but may closely approach unity in some cases for an extended wavelength region. Thus, the spectral distribution is exactly the same as that for a blackbody but the total energy radiated is less. Several solid materials, including platinum, iron, tungsten, and carbon, are very nearly nonselective radiators over a fairly wide range of wavelengths.

6-2.3.1.3 Incandescent Sources

Actual solid radiators are not "black" and their total emission is less than that of a black-

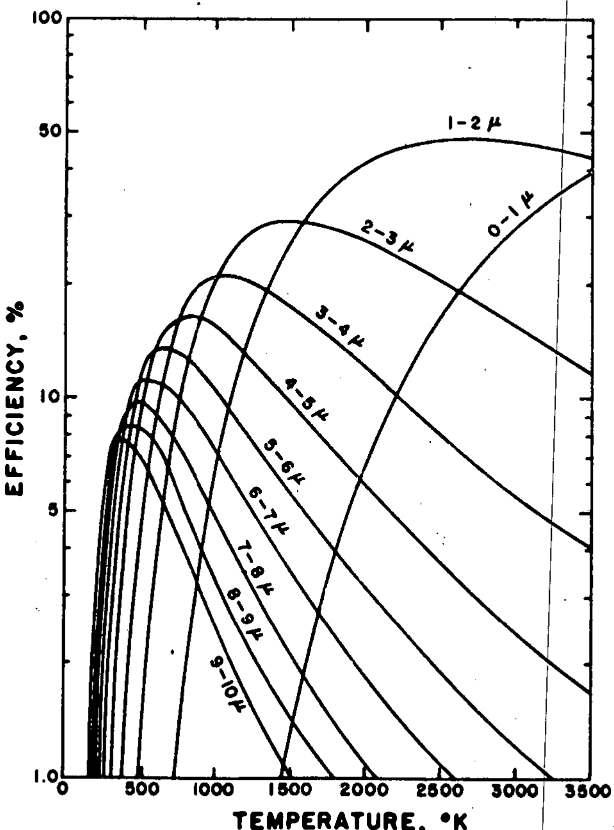

Figure 6-5. Isothermal Efficiencies: Fraction of Energy Emitted by an Isothermal Radiator in Various Wavelength Bands as a Function of Temperature

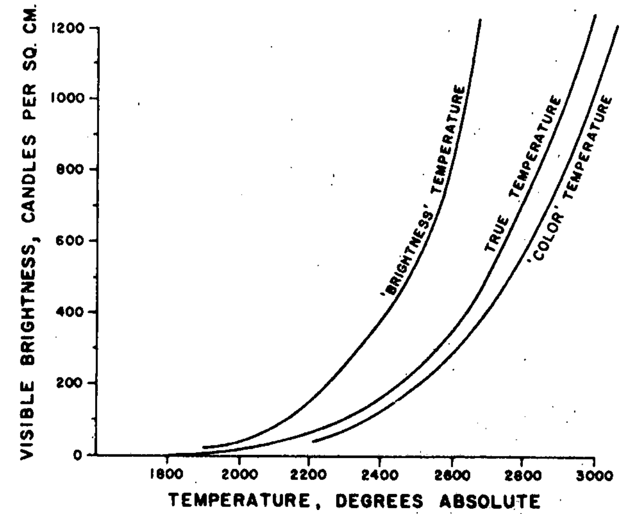

Figure 6-6. "Optical" Temperatures of a Tungsten Filament

body. In addition, their emissivity varies with the wavelength and actual radiators are not graybodies. The radiation is thermal if Kirchoff's Law applies, and the ratio of emissive to absorptive powers is a constant for each wavelength and temperature. Application of this law distinguishes between incandescence or thermal radiation, and luminescence or radiation excited by other methods.[28]

While there are materials, such as carbon, whose emissivity is nearly constant with wavelength, the emissivity of certain other materials is strongly wavelength-dependent. If the emissivity is high in the visible region and relatively low in other spectral regions (especially infrared), a larger portion of the total radiation will be in the visible and the heat-to-light conversion efficiency is improved. As an example, Welsbach mantles, which are impregnated with thorium and cerium oxides, have a low emissivity in the infrared. When heated by a relatively nonluminous flame, a larger proportion of energy is radiated in the visible region. The efficiency of a Welsbach mantle as a light source is also due, in part, to the catalytic activity of the oxides so that the chemical reaction is faster and, therefore, the heat production greater near the mantle.

Temperatures of incandescent sources can be estimated from their total radiation by use of Stefan's Law, according to which the total radiation $= 5.67 \times 10^{-5}\ T^4$ ergs per second per square centimeter. Temperatures determined in this way are called radiation temperatures. If temperatures are estimated from the visible brightness at a particular wavelength, they are called brightness temperatures. If temperatures are estimated on the basis of the best fit of their emission curve to a blackbody in the visible region, they are called color temperatures. While it is possible that temperatures determined by these methods may differ widely, in extreme cases, from the true temperature, the difference is usually less than a hundred degrees for incandescent solids such as furnaces and lamp filaments (Figure 6-6).

6-2.3.2 Luminescence

Luminescence results when a process leads directly to an atom or molecule in an excited state, from which it can return to a lower energy state

by the emission of radiation. Under these circumstances, the radiation produced at certain wavelengths may be much greater than the amount expected due to thermal radiation. Broadly speaking, luminescence refers to the emission of light for any reason other than high temperature.

6-2.3.2.1 Chemiluminescence

If the excited atom or molecule is formed directly as the result of a chemical reaction, the phenomenon is known as chemiluminescence. The emission of formaldehyde bands from the "cool flames" of ether aldehydes and certain hydrocarbons, at temperatures between 200° and 400°C, are due to chemiluminescence. Radiation from the reaction zone of a Bunsen burner, the inner cone, is stronger than can be accounted for thermally, and is due to chemiluminescence. The amount of radiation produced by a pyrotechnic flame which is due to chemiluminescence is difficult to determine and, under certain circumstances, the amount may be significant.

6-2.3.2.2 Phosphorescence and Fluorescence

Certain substances, including the sulfides of calcium and barium, when exposed to radiation, will continue to glow after the radiation source is removed. This phenomenon is known as phosphorescence. In other materials, the glow persists only for a fraction of a second. In the latter case, the phenomenon is known as fluorescence. In general, the radiation emitted by a phosphorescent or fluorescent material is of a longer wavelength than the exciting radiation. In all these cases, absorption of the exciting radiation causes the formation of an escited molecule or atom. The longer wavelength of the emitted light is attributed to the return of the excited particle to the original nonexcited state in two or more steps, rather than by a single transition.

6-2.3.3 Flame Sources[25,26]

The chief distinction between combustion and other chemical reactions is the appearance of flame and the emission of light. Most flames produce an emission spectra of discrete bands which may, especially for luminous flames containing solid particles, be superimposed on a continuous background.

The radiation from any system in complete thermodynamic equilibrium will be continuous and the same as a blackbody at that temperature; however, flame systems do not fit in this category due to their nonequilibrium nature. In most small flames, the emission of radiation by the emitting molecules and particles is not balanced by the absorption of radiation resulting in a steady deactivation of excited molecules and radiation cooling of solid particles. This energy loss must be made up by collision processes in the flame and, if not efficient enough, the distribution of energy between the excited molecules or solid particles may differ from equilibrium conditions. In addition, chemical equilibrium may not be obtained.

The small particles that are formed in many flames, including most pyrotechnic flames, definitely influence the radiation produced by these flames. The continuous background is emphasized and, in many cases, most of the radiation produced is continuous. This continuum produced by particles in a flame differs from that produced by a graybody or blackbody because:

(1) The emissivity of the material which makes up the particles varies with the wavelength.

(2) The scattering of light by the particles changes with wavelength even if the material making up the particle is black or gray.

While most of the radiation produced by flames is thermal in origin, some of the radiation is due to chemiluminescence where the amount of light emission is much greater than that expected from thermal emission. For premixed flames of the "Bunsen" type, the emission from intercanal gases is thermal in origin. For the reaction zone (the inner cone) there is more radiation than can be accounted for thermally.

The characteristics of the radiation produced by all flames, whether they contain small particles or not, will change as the flame size increases. Self-absorption becomes more important and the radiation will approach more nearly that of a blackbody.

6-2.4 PHOTOMETRY

Photometry is the science of measuring light. Since the eye is very sensitive and nonlinear in its response to radiation, an arbitrary unit, the lumen, is used to evaluate radiant electromagnetic flux in

terms of its visual effect. The lumen has the same dimensions as power. It has been found by experiment that, for the so-called normal observer, one lumen is equivalent to 0.00161 watt of monochromatic green light of a wavelength corresponding to the maximum in the visibility curve, 555 millimicrons. The number of lumens produced by one watt of radiant power is called the luminous efficiency of the source. For a monochromatic source, the luminous efficiency is obtained by multiplying the relative visibility for the wavelength in question by 680 lumens/watt.[29]

6-2.4.1 Instruments for Measuring Light Intensity

Instruments used for the measurement of light intensity can be divided into two general categories: (1) those which use the heating effect of the radiation, and (2) those which make use of quantum effects of the radiation.

In the first category, the radiation absorbed by the receiver raises its temperature which is sensed by some appropriate means. The thermocouple uses the thermoelectric effect while the bolometer uses the change in resistance of a resistance element, which may be a semiconductor, to sense this temperature rise. Generally, both of these detectors are spectrally nonselective in their response to radiation, i.e., they absorb like graybodies. In another type of thermal detector, which may be selective in its response, the radiation is absorbed by a gas. The temperature change produced in the gas, which is confined to a very small volume, is sensed as a pressure rise.

The second category of detectors are the photodetectors which, in principle, count the number of quanta of radiation. An example of a common detector in the second category is the photocell which is a photoemissive detector. It depends for its operation on the ejection of electrons from a specially prepared surface by the incident quanta of radiation. In a vacuum photocell the response to incident radiation is a linear function of the light intensity. The electrons emitted are drawn to the anode from the sensitized cathode by a relatively small voltage applied to the electrodes. Gas-filled photocells are nonlinear in their response to incident light intensity, but are more sensitive than the vacuum type because ionization of the gas by collision can be utilized to increase the number of electrons reaching the anode for a given amount of incident light. Still more sensitive photocells, known as photomultipliers, use the phenomenon of secondary electron emission to produce an internal amplification of the order of one million. In all cases, the response of the photocathode surface is spectrally selective and is determined by the basic material and its preparation. Another type of light-sensitive cells is the photoconductive cell, in which the action of light causes an increase in the electrical conductivity of the device. The selenium cell is an example. A third type of detection utilizes the photovoltaic effect in which a voltage is produced across the interface separating a semiconductor from a conductor by light incident on the interface. A common example of this type of detector is the copper-cuprous oxide cell. All of these detectors—photoemissive, photoconductive, or photovoltaic—have a selective spectral response, as do photochemical reactions, including photography. The spectral response of photochemical reactions is selective because only the light which is absorbed will produce a photochemical effect. Actiometers use photochemical reactions in which the quantum yield, which is equal to the number of induced reactions divided by the number of quanta absorbed, has been accurately determined.

6-2.4.2 Measurement of the Light Output of Flares

Flare output measurements are usually made in a photometric tunnel. This tunnel is a light-tight structure with a fan to remove smoke and with instruments to measure the brightness, color, and burning time of a flare. The inside of the tunnel is usually flat black and baffled to eliminate reflections. The tunnel is usually built in three parts: a burning room, which contains the burning table, ignition apparatus, and exhaust fan; a long tube section from 50 to 100 feet long which houses the photometric transducers; and an instrument room, which houses the recording instruments and provides a place for the personnel to work. More complete measurement capability for a tunnel would include the ability to determine the visible spectral output of flares, ultraviolet and infrared outputs, and flame temperatures. The tunnel must have calibrating lights and color filters for calibra-

tion of the instruments. Luminous intensity measurements in terms of candlepower are often determined by an instrument which consists of a barrier layer photocell, filters, and a microammeter. This illuminometer is placed at an accurately known distance from the point at which the candle or assembly is to be burned and is then calibrated by means of a standard incandescent white light source. During the burning of the item, illuminometer readings are taken at predetermined time intervals throughout the burning period and the average of these readings is calculated. In many cases the output of the detector is displayed on a graphic recorder. In this case, the output of the photocell is fed into the recorder which has been calibrated so that the anticipated light output will produce a nearly full scale reading. A graphic record is superior to readings taken with an illuminometer because all variations during burnings are recorded and thus are available for future study. The area under the curve thus obtained represents the candlesecond value of the tested item. An integrator, which gives the candlesecond value of the composition directly, is coupled with the photocell, thus avoiding the time consuming and less accurate method of estimating or planimetering the graphic record.

The state of the science in photometry is not yet precise, and measurement errors within $\pm$ 10% on flares are as good as can now be attained. Specification MIL-C-18762 covers general requirements although later refinements have been made at each military installation. Representative facilities for these measurements are to be found at Picatinny Arsenal, Dover, New Jersey; Naval Ammunition Depot, Crane, Indiana; Naval Ordnance Test Station, China Lake, California; and Naval Ordnance Laboratory, White Oak, Silver Spring, Maryland.

6-2.4.3 Intensity

The intensity of a point source, in any direction, is defined as the light flux in lumens per unit solid angle (per steradian) in that direction, or

$$I = \frac{dF}{d\omega} \tag{6-10}$$

where I is the intensity in candela and dF is the lumens of flux within a small solid angle of $d\omega$ steradians. A unit point source, emitting light uniformly in all directions, radiates 4π lumens. The unit of luminous intensity—adopted by the International Commission on Illumination in 1948—is the candela. It is of such a magnitude that a blackbody radiator at the temperature at which pure platinum solidifies has a luminance of 60 candela per square centimeter.[30] An earlier unit of luminous intensity, the candle, is equal to 1.02 candela. Another unit, candlepower, also has been widely used to express the luminous intensity of a light source. While the use of these units should be discouraged, they have been widely used by many pyrotechnic investigators. Therefore, the terms candela (preferred), candle, and candlepower will be used interchangeably in this handbook.

6-2.4.4 Brightness

The concept of brightness is required because most sources are not points and the concept of intensity is not readily applicable to extended sources. The brightness of an extended source is expressed in candela per square centimeter of emitting surface.

6-2.4.5 Illumination

The illumination of a surface is the amount of light flux (lumens) incident upon a unit area of surface. An illumination of a lumen per square foot is called a foot-candela. The illumination E of a spherical surface of radius r, enveloping a point source of intensity I, is given by:

$$E = \frac{F}{A} = \frac{4\pi I}{4\pi r^2} = \frac{I}{r^2} \; \frac{\text{lumens}}{\text{unit area}} \tag{6-11}$$

for a plane surface at a distance x from a point source of intensity I:

$$E = \frac{I}{x^2} \cos\theta \tag{6-12}$$

where θ is the angle between the source vector and the normal to the surface.

6-2.4.6 Photometric Units

The units employed in photometry are a continuing source of difficulty, especially for the novice. A strong effort is being made to secure greater uniformity, reduce the number, and pro-

TABLE 6-1
CONVERSION FACTORS FOR PHOTOMETRIC UNITS

Physical *Radiator-source of Radiant Energy*			*Phycho Physical* *Luminator-source of Luminous Energy*		
Radiometry	*Symbol*	*mks units*	*Photometry*	*Symbol*	*mks units*
Radiant			*Luminous*		
energy		joule	energy	Q	talbot
density		joule/m^3	density	q	talbot/m^3
flux		watt	flux	F	lumen
emittance	W	watt/m^2	emittance	L	lumen/m^2
intensity		watt/sterad	intensity	I	lumen/sterad
radiance	N	watt/sterad-cm^2	radiance	B	lumen/sterad-m^2
irradiance	H	watt/m^2	illuminance	E	lumen/m^2
Spectral reflectance			*Luminous reflectance*	r	
Spectral transmittance			*Luminous transmittance*	t	

Illumination
1 lumen/ft^2 = 1 foot-candle = 10.764 lumen/$meter^2$ = 10.764 lux
1 lumen/$meter^2$ = 1 meter-candle = 1 lux — 10^{-4} phot
Brightness
1 foot-lambert = 1 equivalent foot-candle
1 lambert = 3183 candle $meter^{-2}$ = 296 candle ft^{-2} = 2.054 candle $inch^{-2}$
Exposure
1 meter-candle-second = 1 lumen-second $meter^{-2}$

vide more logic in photometric units.[7,8] Some of the more common photometric units are summarized in Table 6-1. The units of photometry are often applied, incorrectly, to measurements of infrared or ultraviolet radiation, or to describe the sensitivity of photographic emulsions to radiation. Such usage should be avoided and radiometric units used for these spectral regions.

6-2.5 COLOR[81,82]

In a physical sense, color is determined by the wavelength(s) or spectral energy distribution contained in a light beam. Physiologically, color is the sensation produced as the result of the excitation of the retina of the eye by these waves. Colors are compared in terms of hue, saturation or purity, and brightness; all of which influence the color sensation produced. Hue refers to the color, i.e., red, green, or blue. Not all hues are observed in the spectrum of sunlight. The purples are notably absent. The sensation is a measure of the content of white light; only monochromatic colors are completely saturated. Brightness or lightness is a measure of the amount of light being emitted or reflected from the colored light sources or colored object. Brightness applies to luminous sources while the term lightness refers to color seen because of reflected light. These three aspects of color can be represented on a color solid (Figure 6-7) where hue changes around the circle, lightness increases upward, and saturation increases outward from the axis.

6-2.5.1 Additive Color

In principle, it is possible to produce any hue by a suitable combination of three primary colors, one from the middle of the visible spectrum, green, and one from either end, blue-violet and red. As indicated by the additive color circles in Figure 6-8, proper proportions of red and green light will produce yellow. If the proper amount of blue-purple light is added, white light is produced.

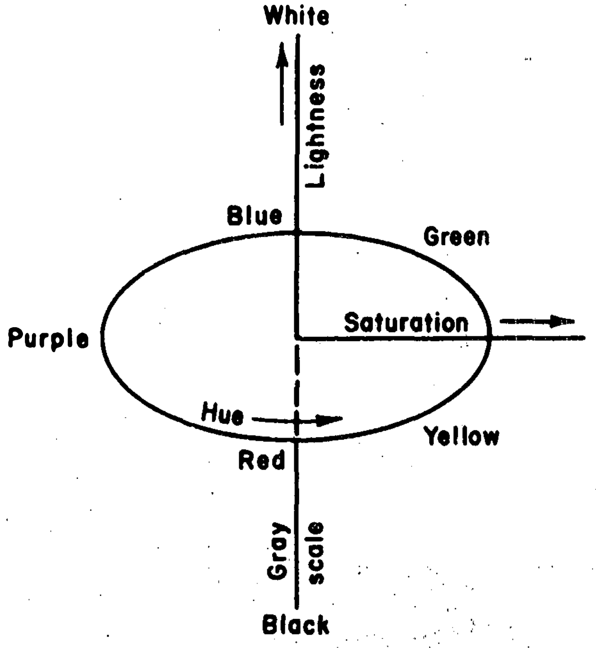

Figure 6-7. Dimensions of the Psychological Color Solid

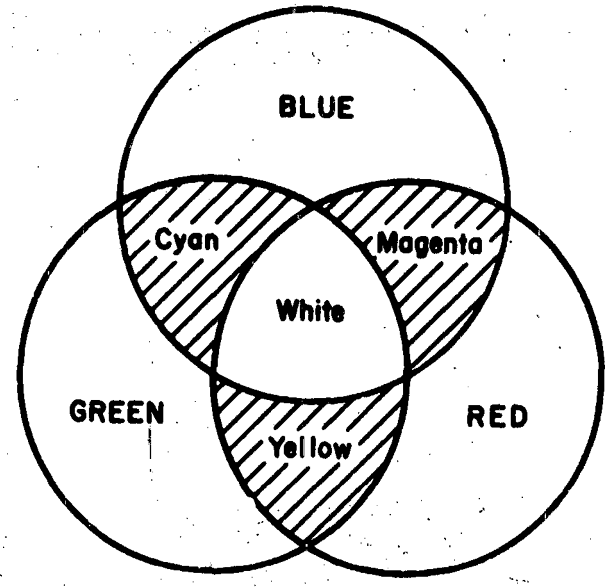

Figure 6-8. Additive Mixture of Primary Colors

Colors such as yellow and blue-purple, that produce white light when added together, are called complementary colors. The complementary color for red is a blue-green (cyan), for green is a red-purple (magenta), and for blue-purple is, as indicated earlier, yellow.[7]

6-2.5.2 Subtractive Color

The light incident on a nonluminous object may be partly reflected, partly absorbed, and partly transmitted. If the incident light is white, the transmitted light will be the color which is complementary to the color which is selectively absorbed. For example, the light transmitted will be red if blue-green is selectively absorbed. Opaque bodies, which are seen because light is diffusely reflected from them, also appear colored because of selective absorption of light which penetrates a short distance beneath the surface before it is reflected.

6-2.5.3 Chromaticity Coordinates

The tridimensional color stimulus required by the eye has been studied in detail and has led to a precise method for expressing a particular light type. It was found that only the mutual ratios of three primary colors are of importance in determining the "color according to the eye" of a given light type. These ratios may be described by expressing each primary as a part of the total impression of the light type obtained by the eye. Thus, for red, green, and blue, respectively, the ratios are:

$$\frac{r}{r+g+b};\ \frac{g}{r+g+b};\ \frac{b}{r+g+b}$$

which necessarily total one, and, as a result, only two need be designated to determine the light type. A particular color or color point, therefore, may be displayed on an x-y plane, and, due to the mutuality of the components, will fall within an area bounded by a 45-degree triangle. However, the actual area containing color points varies with the particular set of color sensitivities used to determine the color points of the various light types. Each set produces a "color triangle" with its own shape.

In order to effect a standardization, the International Commission on Illumination (I.C.I.),* in 1931, recommended that all subsequent color data

* Now known as C.I.E., Commission Internationale de l'Eclairage.

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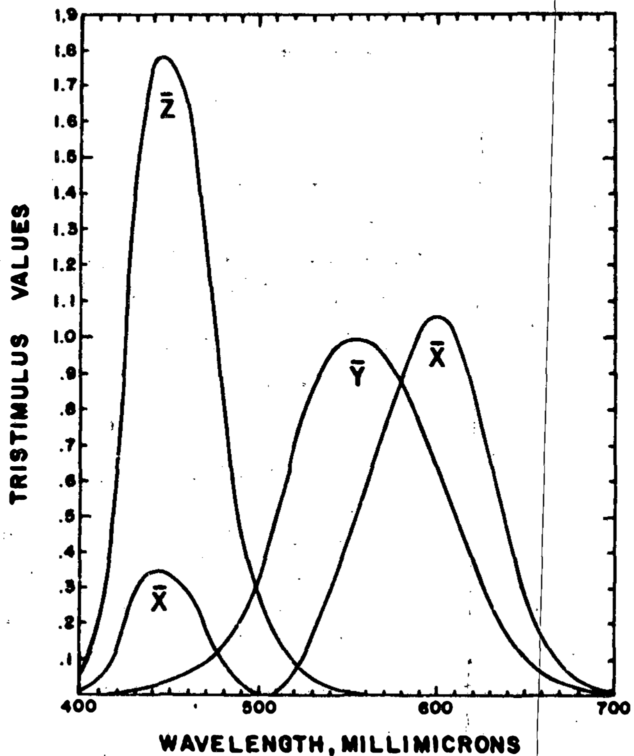


Figure 6-9. Tristimulus Values of the Spectrum Colors According to the 1931 I.C.I. Standard Observer

be expressed in terms of the same tristimulus system so that the results would be immediately comparable. The Standard Colorimetric Coordinate System (X, Y, Z color triangle) was introduced which is based on the color sensitivity curves shown in Figure 6-9. These curves are the result of color comparison tests conducted on many observers and compiled to produce those for the "standard observer." The primary colors were selected so as to produce no tristimulus value less than zero (avoiding the use of negative values in computations). Further, the curve for the Y-factor is identified with the eye-sensitivity curve for light, which forms the basis of photometry. The values of X, Y, Z are the amounts of the three I.C.I. primaries required to color match a unit amount of energy having the indicated wavelength. The chromaticity coordinates for each wavelength are obtained from the values of X, Y, and Z by means of the ratios:

$$x = \frac{X}{X+Y+Z}, \quad y = \frac{Y}{X+Y+Z}, \quad z = \frac{Z}{X+Y+Z}$$

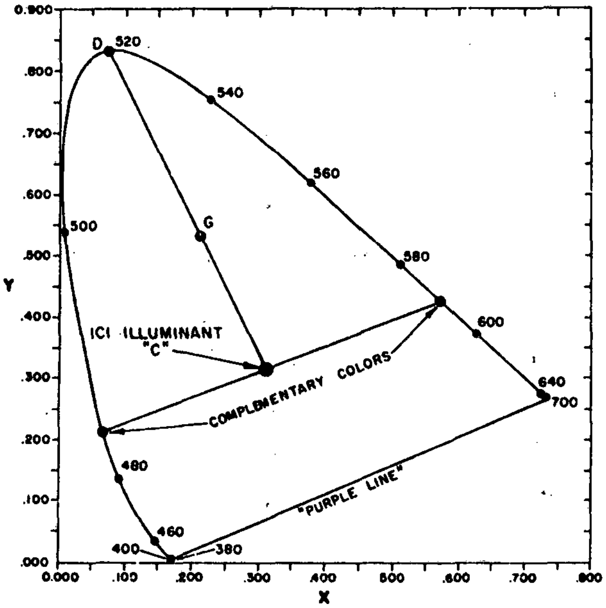


Figure 6-10. C.I.E. Chromaticity Diagram

Since, as indicated earlier, only two coordinates are required to describe the light type, the values of X and Y are plotted on a chromaticity diagram (Figure 6-10) and form a loci of monochromatic spectrum colors. The line drawn between 380 millimicrons and 700 millimicrons forming the "base" of the triangle is called the "purple line" along which no perceptible colors exist. The center of the triangle (C) is the equal energy or "white point" and has been designated by the I.C.I. (or C.I.E.; used interchangeably) as the light produced by "Illuminant C" which corresponds very closely to average daylight. Complementary colors will fall on a straight line passing through Illuminant C. Also, any color can be considered as a mixture of Illuminant C and spectrum light having a wavelength given by the intersection of a straight line through Illuminant C and the given color G, with the Chromaticity Curve D (Figure 6-10). This wavelength D is called the dominant wavelength. In addition, a mixture of two color points anywhere on the diagram will produce a color which is located on a line between the two initial colors. Other useful aspects of the Chromaticity Diagram can be found in the references.[32]

The assignment of chromaticity coordinates to

a particular light source is not an easy task. Theoretically, this can be accomplished for the Y value by multiplying the ordinate of the Y curve in Figure 6-10 at each wavelength by the radiant flux of the light source at the wavelength and summing over the visible spectrum. The X and Z values may be found by a like process and the chromaticity coordinates x, y and z can be calculated. In practice, it is difficult to match exactly the I.C.I. tristimulus curves; however, several methods have been suggested[81] which give fairly good results. The more widely used methods incorporate barrier layer photocells and correction filters.

6-2.5.4 Munsell Color System[81]

The Munsell color system specifies a surface color by giving, for usual viewing conditions, its position on a more or less arbitrary hue (Munsell hue), lightness (Munsell value), and saturation (Munsell chroma) scales having nearly perceptually uniform steps. The Munsell value varies from zero for an ideal black surface having a luminous reflectance equal to zero, to ten for an ideal white diffusing surface having a luminous reflectance equal to one. Munsell chroma is expressed in arbitrary units intended to be perceptually of the same size regardless of value and hue. The strongest known pigment colors have chromas of about 16 neutral grays; black and white have a zero chroma value. Munsell hue is expressed on a scale intended to divide the hue circle (red, yellow, green, blue, purple, and black to red) into 100 perceptually equal steps.

The pocket edition of the Munsell Book of Color has been widely used as a color standard. It consists of forty constant hue charts where all color samples making up a chart have the same hue. The color samples making up the chart are arranged in rows and columns, the rows being chroma at constant Munsell value and the columns being value scales at constant Munsell chroma. Comparison of an unknown color with these two families of scales gives, by interpolation, the Munsell value and Munsell chroma of the unknown color. Interpolation between the constant hue charts gives the Munsell hue.

6-2.5.5 Color Value

A commonly used designation for describing the color of a pyrotechnic composition is the color value. This is defined as the ratio of the apparent light intensity (through specific filters) to the total (or unfiltered) intensity. This is usually accomplished through the use of two photocells, one of which is equipped with a glass filter. The ratio obtained is a measure of the visual depth of color of the flame.

6-2.6 ATMOSPHERIC EFFECTS

Absorption and scattering can change the energy distribution of light passing through the atmosphere. While the absorption in parts of the ultraviolet and infrared regions may be very large, the more important effects in the visible region are due to scattering. A light beam passing through a length x of the atmosphere is attenuated from the initial flux F_o, to a flux F, by an amount which depends mainly on the scattering coefficient σ, even though individual layers may absorb light.

$$F = F_o e^{-\sigma x} \tag{6-13}$$

For particles whose radii are less than approximately $1/10$ the wavelength of the light λ, the scattering coefficient σ can be approximated by:

$$\sigma = A\lambda^4 \tag{6-14}$$

where A is effectively a constant. The theory for spherical particles comparable in size to the wavelength of light results in extremely complicated expressions for the scattering coefficient.

As discussed in greater detail in Paragraph 7-2.1.1, smaller droplets preferentially scatter the shorter wavelengths so that the color of the transmitted light will shift toward the red. The preferential scattering of the shorter wavelengths decreases with increasing particle size until the particle radii become slightly greater than that corresponding to the maximum for red light. At this time the transmitted light appears blue or green. There is little preferential scattering for particles whose radii are greater than one to two microns. Little or no variation in transmission with wavelength is observed for fogs or thin clouds because their drop size distribution is broad. If the scattering particles are polydispersed, but

smaller than optimum size, the transmitted light will be more red than the incident light, accounting for the deep red of the transmitted light from the setting sun.

6-3 CONSOLIDATED ILLUMINATING DEVICES

A consolidated illuminating composition is formed by mechanically pressing, extruding, or casting finely divided illuminating composition into some solid shape which often has a candle-like form. When such an item burns in a propagative fashion, the flame radiates energy in the ultraviolet, visible, and infrared region of the spectrum.. In most cases, less than 10 percent of the radiant energy is in the visible region. The distribution and relative intensity characteristics of the radiation produced, in any given region of the spectrum, are determined basically by the products of the burning reaction which emit in that region and the temperature reached by the emitting species.

Light-producing pyrotechnic devices are characterized for military purposes by luminous intensity, color value (hue and saturation) of the flame, and burning rate. Sensitivity of the composition to impact, static electricity, and friction should be a minimum for safety. The ignition temperature, ignitibility, stability, and hygroscopicity are important in determining the certainty of functioning.

6-3.1 ILLUMINATING FLARES

An illuminating flare produces a single source of illumination which is generally of high candlepower and substantial duration. Flares may be parachute-supported, towed, or stationary. While their primary function is illumination, they may be used for identification, ignition, location of position, or warning.

In general, a pyrotechnic illuminating flare should:[33] (1) produce essentially white light, (2) have an intensity in foot candles adequate to produce a brightness level from 0.1 to 1.0 foot-lambert on areas or targets with minimum reflectivity, and (3) burn at peak intensity for a minimum of thirty seconds and, preferably, in excess of one minute. (These values are desirable; however, where necessary, lower levels may be adequate. Illumination above 1.0 foot-lambert will generally require an unreasonable amount of illuminant.) Although it is often difficult to produce, white light provides the best illumination for the greatest range of possible conditions in the field. Since illuminating flares are used under field conditions where the location and recognition of unfamiliar objects are important, sufficient duration and intensity are required to complete the visual observation and to distinguish objects in the field from their background. Candlepower requirements necessary or adequate illumination, 0.1 to 1.0 foot-lambert, fl, when the flare is suspended above the ground, are given in Table 6-2.[33]

TABLE 6-2
CANDLEPOWER REQUIREMENTS VERSUS HEIGHT OF ILLUMINATING SOURCE

Height Above Ground	*Ground Brightness, 0.1*	*1.0*
100 ft	1,000*	10,000*
500 ft	25,000	250,000
1000 ft	100,000	1,000,000

* Candlepower requirements necessary to provide specified illumination (0.1 and 1.0 fl) on the ground from given heights above the ground.

A diagram of a parachute suspended flare is shown in Figure 6-11 indicating the manner in which ground illumination E may be approximated from values of h, the height of the source; r, the radius of the desired illumination; and I, the intensity of the source. Intensity curves for various heights to produce a minimum value for E of .025 foot-candle are shown in Figure 6-12.

6-3.1.1 Aircraft Flares

Flares for aircraft provide illumination for reconnaissance, observation, bombardment, landing, and also targets for practice firing of antiaircraft guns. While details of flares vary with their purpose, flares for illumination have certain characteristics in common in that they all produce high-intensity white or colored light for an appreciable length of time. Most aircraft flares are parachute-supported to retard their speed of fall and thus provide illumination over a given

TABLE 6-3
CHARACTERISTICS OF VARIOUS ILLUMINATING FLARES

Item	*Method of actuation*	*Time lapse from actuation to full function, sec*	*Burning time, sec*	*Candle-power, 10^3*	*Fall, fps*	*Max L, in.*	*Max dia, in.*	*Weight, lb*	*Max speed of airplane at time of release, mph*
FLARE, AIRCRAFT: guide, 1 min T6E1 (white) T7E1 (red) T8E1 (green)	Electricity	6 to 7	45 to 60	650 700 90	....	5.4	5.46	....	....
FLARE, AIRCRAFT: parachute M8A1 (w/o suspension bands) (emergency night landing) M8A1 (training) (w/o suspension bands)	Release from airplane	3.0 to 5.0	165 to 195	350	8.0	25.42	4.25	17 6	200
M9A1	Fired from PISTOL, pyrotechnic, AN-M8	2.5	60 to 70	60	7.0	15.05	2.0	2.11	200
M26A1 (AN-M26) or M26 M26A1 (AN-M26) or M26 (w/blue band)	Released from airplane	5 to 92	195±15	800 575	11.6	50.0 (fuzed)	8.0	52.5	150 (M26) 350 (M26A1)
M138 (T10E4) M139 (T10E6)		5 to 92	360 180	1,500 3,000	10	45.6	6.25	62	440
Mk 5 and Mods		variable	180	600	....	27.0	4.75	18.0	....
Mk 6 Mod 5 Mk 6 Mod 6		variable	180	1,000	....	35.75	5.37	30.0	....
AN-Mk 8 Mod 1 AN-Mk 8 Mod 2		90 120	180	500	8.0	25.12	4.75	18	250
3 minute, electrically operated	....	1½	180	200	9.1	28	4.5	22	....
3 minute, Wiley SA 8	....	....	....	....	....	....	....	....	....
FLARE, AIRCRAFT: tow-target, M50		0	360	65	....	22.8	2.62	7.13	120
FLARE, AIRCRAFT: towed Red, M77 (T18) Amber, M78 (T19) Green, M79 (T20)	Tow cable attached to airplane.	0	360±30	225 70 90	....	23.34	4.55	21	200
FLARE, SURFACE: Airport, M76	Hand or electric squib	0	300 to 420	600 to 850	....	31.33	4.26	27.6	
Parachute, trip, M48	Pressure or trip wire	3	20	110	3	9.75	5.5	5.0	
Trip, M49	Trip wire	0	55	40	....	6.75	3.0	1.5	

area for a greater time interval. Aircraft flares also have some form of delayed ignition so that they will clear the aircraft and function at a desired altitude below it. Certain flares designed for use below the aircraft, such as those intended for bombing purposes, are provided with shades to shield air-crew members from glare. Data for several aircraft flares are presented in Table 6-3. A typical aircraft parachute flare for night bombardment is shown in Figure 6-13, and its opera-

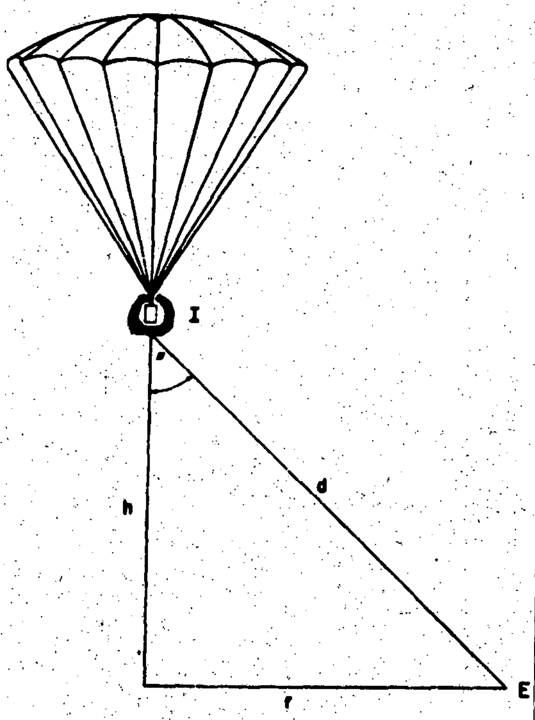


Figure 6-11. Illumination Diagram for Parachute Suspended Flare

tion is shown diagrammatically in Figure 6-14. A typical tow-target flare is illustrated in Figure 6-15.

6-3.1.2 Surface Flares

Flame-type surface flares are used for illumination during airplane landings in case of power failure at airports, or to outline boundaries of emergency landing fields. Mine- or grenade-type surface flares are used to illuminate targets and objectives, to aid in detection of infiltration or surprise attacks by enemy troops, and for recognition and signaling purposes. Data on several of these flares are presented in Table 6-3. A surface flare which is primarily used to give warning of infiltration by enemy troops is shown in Figure 6-16.

6-3.2 ILLUMINATION SIGNALS

Light-producing signals are much smaller and faster burning than flares and may consist of a single parachute-supported star or from one to five freely falling stars, with or without colored tracers. To be effective, any signal must be recognized in addition to being detected. Characteristics of illuminating signals which are important in determining their effectiveness include intensity, duration, and the hue and saturation of the color.[38]

Illumination signals are used during the day as well as night. The brightness of the daylight sky requires a signal of increased intensity to provide adequate contrast. Depending on the location of the signal relative to the clouds and sun, and the brightness of the sky; the intensity of a signal adequate for night use must be increased by a factor of ten (twilight) to over 100,000 (bright daylight). Relatively little is known concerning the effects of flame duration on the detection and recognition of pyrotechnic illuminating signals. However, the burning time should be of sufficient duration that the signal can be detected, and the color should be of sufficient saturation so as to be recognized in a relatively short period of time.

Since color differences are often the basis for communication by signal flares, the relative effectiveness of the various color hues and their saturation is important. Since a signal used during daylight must often be observed against a sky (blue) background, red signals, even though requiring slightly more intensity at night, are most visible and most easily recognized in general usage.[38] Of the other methods, such as multiplicity, different shapes, sizes, patterns, or flashing of the signal—which could be used for communications —only multiplicity appears to be flexible enough for normal combat use.

6-3.2.1 Aircraft Illumination Signals

Aircraft signals used directly in connection with combat operations were originally intended for signaling from air to air or air to surface. Since the introduction of the pyrotechnic pistol and hand pyrotechnic projector, aircraft signals have also been used by ground troops for ground-to-ground and ground-to-air signaling. The signals are generally of one piece, rimmed case construction with a steel closing cap. Aircraft signals are fired from the pyrotechnic pistol or hand pyrotechnic projector.

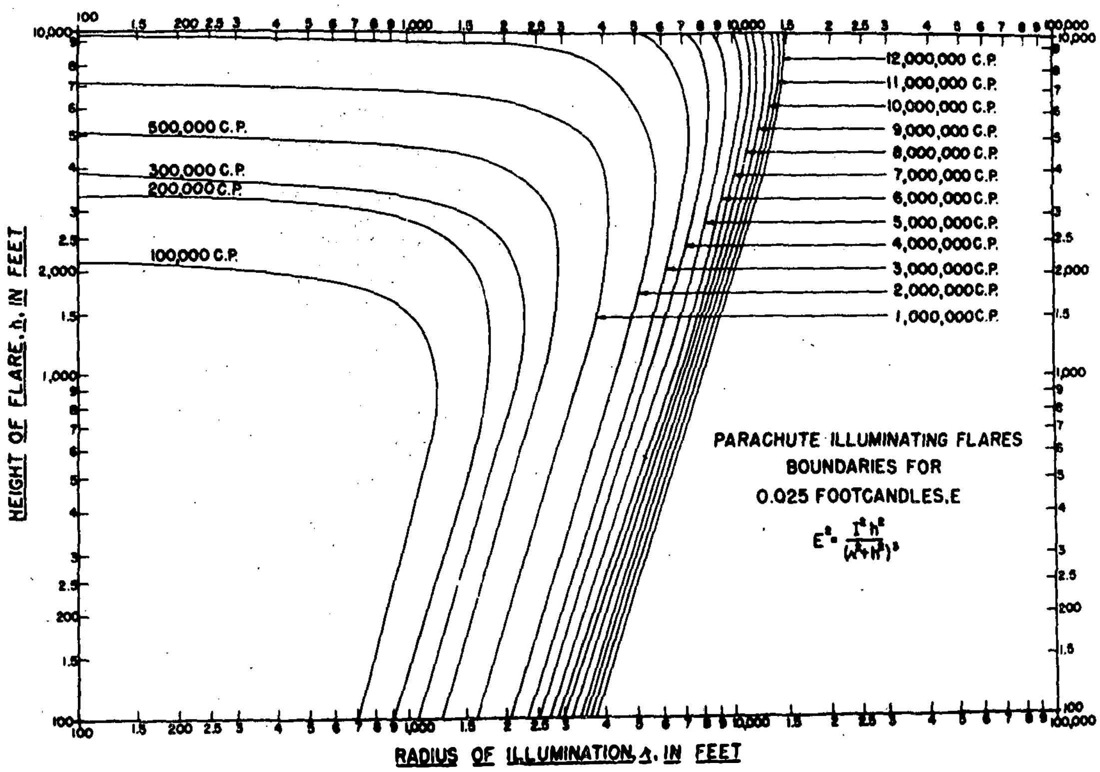


Figure 6-12. Intensity Curves for Various Parachute Flare Heights

Single-star aircraft signals, double-star signals, and tracer double-star signals contain red, green, or yellow light-producing candles of pyrotechnic composition. Stars can be distinguished at distances up to five miles at night and two to three miles in daylight.

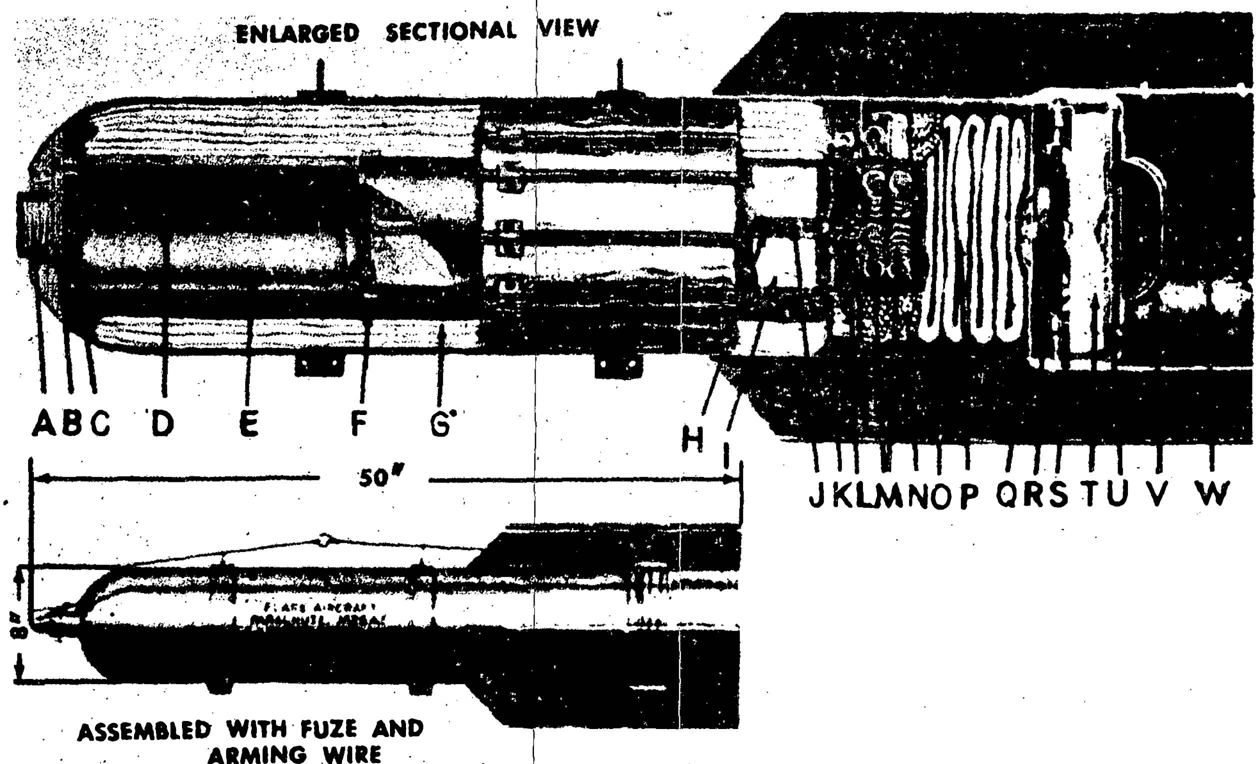
Data on aircraft signals are presented in Table 6-4(A).

6-3.2.2 Ground Illumination Signals

These signals consist of devices which produce a signal when fired vertically into the air. The height of projection is from 600 to 700 feet. Data for some ground illumination signals are given in Table 6-4(B). A typical hand-held device is shown in Figure 6-17.

6-3.3 TRACERS

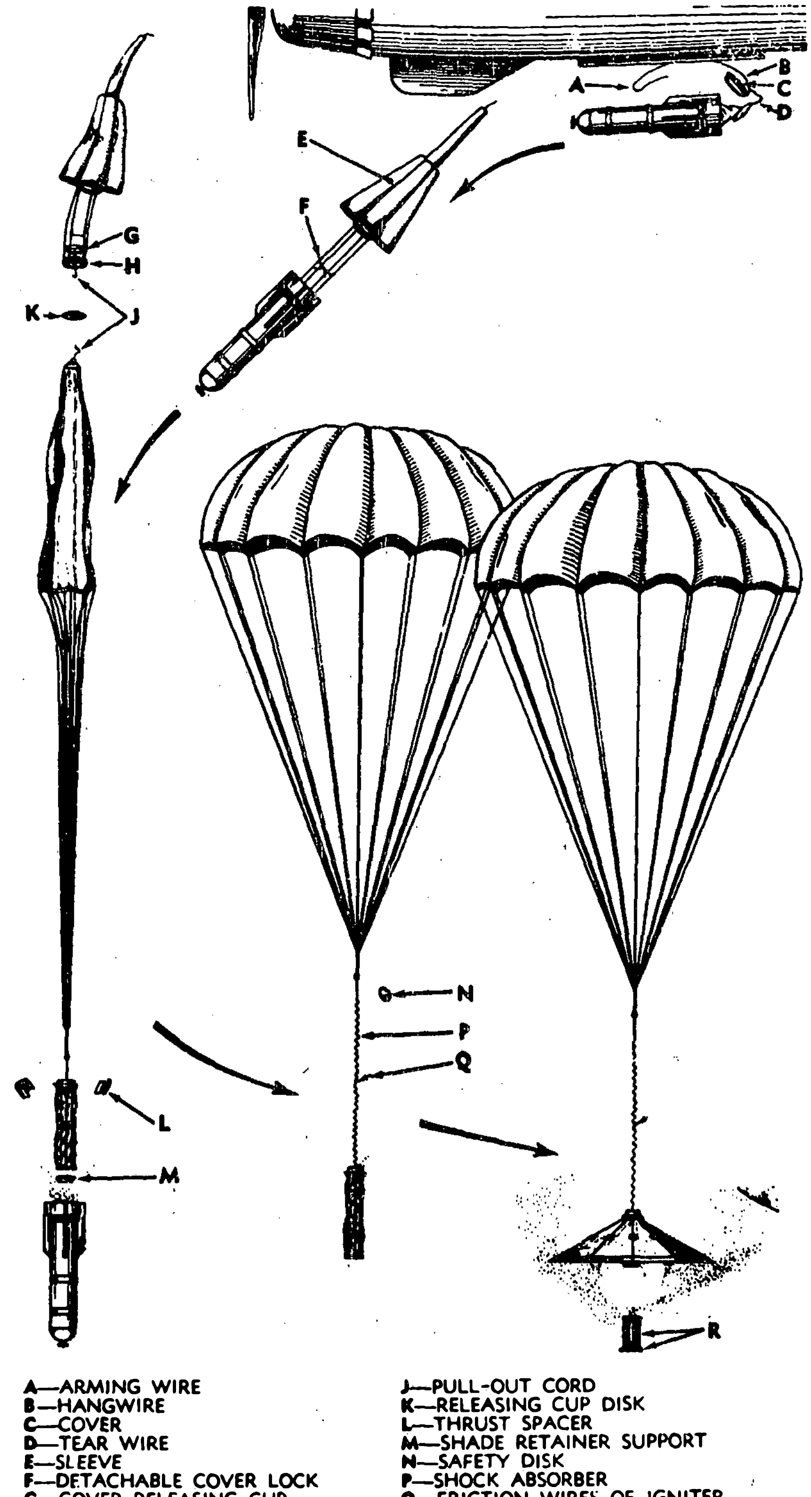
Tracer ammunition for both small arms and artillery is used for determining range and directing fire. In some small arms tracers the gilding metal or steel bullet jacket has, as shown in Figure 6-18, a cavity into which the tracer and its associated igniter compositions are loaded and compressed at 80,000 to 125,000 psi. Armor-piercing tracer ammunition contains a steel core which is inserted into the bullet jacket, as shown in Figure 6-19. The steel core has a cavity into which the tracer compositions are loaded. Some artillery projectiles have a cavity in the base into which the tracer and igniter compositions are pressed, as shown in Figure 6-20, at a pressure of over 100,000 psi. Other artillery projectiles use a separately-loaded tracer assembly which is fitted into the base of the projectile as illustrated in Figure 6-21. In some ammunition, the tracer composition initiates a charge which destroys the projectile after a definite time interval. In specific cases, this may be the only function performed by the composition loaded in the tracer cavity.



A	Shipping plug	I	Flare charge	Q	Releasing cup disk
B	Shade retainer support	J	Relay charge	R	Cover releasing cup
C	Rib retainer	K	Delay element	S	Cover
D	Stem	L	Base block assembly	T	Stabilizing sleeve
E	Lower spacer	M	Shock absorber assembly	U	Hangwire
F	Ribs	N	Shrouds	V	Handle assembly
G	Shade	O	Thrust spacer	W	Fin stiffener
H	Quickmatch	P	Parachute		

Figure 6-13. Typical Aircraft Parachute Flare

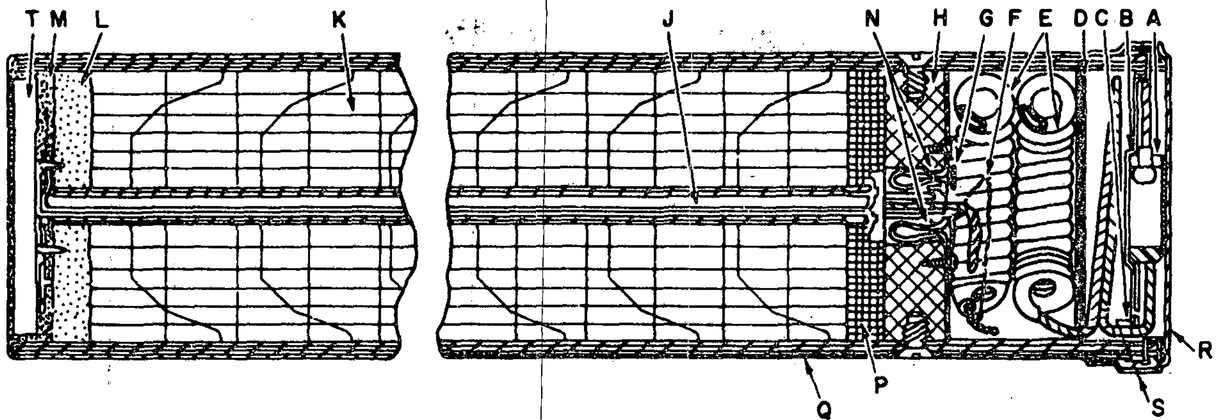
Since tracer compositions are relatively difficult to ignite, a more easily-ignitible ignition composition is loaded on top of the tracer composition. The ignition composition, which usually contains a binder, along with a thin metal seal, serves to protect the tracer composition from the effects of moisture. If the brilliant light from the igniter composition dazzles the gunner and betrays the location of the weapon, a so-called "dim igniter"[10] composition may be used.



A—ARMING WIRE
B—HANGWIRE
C—COVER
D—TEAR WIRE
E—SLEEVE
F—DETACHABLE COVER LOCK
G—COVER RELEASING CUP
H—DETACHABLE COVER
J—PULL-OUT CORD
K—RELEASING CUP DISK
L—THRUST SPACER
M—SHADE RETAINER SUPPORT
N—SAFETY DISK
P—SHOCK ABSORBER
Q—FRICTION WIRES OF IGNITER
R—LOWER SPACER AND RIB RETAINER

Figure 6-14. Operation of Typical Aircraft Parachute Flare

The pyrotechnic behavior of tracer compositions is similar to that exhibited by other consolidated compositions and the same characteristics are important. Tracer pyrotechnic compositions should, in general: (1) produce maximum light output and saturated color for maximum visibility, (2) burn long enough to permit the projectile to be followed to the target, and (3)



A- CABLE RING
B- PULL COVER
C- SLEEVE
D- SAFETY DISK
E- SHOCK ABSORBERS
F- FRICTION WIRE PULL WIRES
G- RETAINER
H- BASE BLOCK
J- QUICKMATCH
K- ILLUMINANT CHARGE
L- FIRST-FIRE CHARGE
M- PRIMING COMPOSITION
N- IGNITERS
P- FIRE CLAY TOP SEAL
Q- FLARE CASE
R- CLOSING COVER (TOP)
S- SEALING STRIP
T- CLOSING COVER (BOTTOM)

Figure 6-15. Typical Aircraft Tow Target Flare

ignite easily from the igniter composition but resist ignition by any propellant gas which may penetrate to the tracer composition. Most tracers are made to produce red light because red light is the most visible color under daylight conditions; however, wide use of white tracers had also been made by the Germans and Japanese. At times there may be requirements for several different colors to indicate origin of the projectiles.

Smoke tracers (Paragraph 7-1.3) have been proposed and developed to provide a more visible trace in daylight; however, the advantages do not justify providing two types of ammunition with different tracers.

6-3.4 TYPICAL COMPOSITIONS

Pyrotechnic illuminating compositions, like other pyrotechnic compositions, are basically a mixture of an oxidizing agent and a metal fuel. Other materials are added to this mixture to modify the burning rate, color, and radiant output, as well as to increase handling safety. Important additives include:

(1) Color intensifiers which are mainly highly chlorinated organic compounds, e.g., hexachloroethane (C_2Cl_6), hexachlorobenzene (C_6Cl_6), Dechlorane ($C_{10}Cl_{12}$), and polyvinylchloride (CH_2-$CHCl$).

(2) Binders which include resins, waxes, elastomers, plastics, and oils.

(3) Waterproofing agents which usually are resins, waxes, plastics, oils, and dichromating solutions. (They are used as protective coatings on metals such as magnesium to reduce the amount of reaction with atmospheric moisture.)

(4) Retardants which are usually inorganic salts, plastics, resins, waxes, and oils. (They are used to decrease the rate of the reaction between the fuel and the oxidant so as to obtain the desired overall burning rate.) Some retardants behave merely as inert diluents while others participate in the reaction at much slower rates than the main constituents.

Typical illuminating, signaling, and tracer compositions are given in Tables 6-5(A) and 6-5(B).

6-3.5 FACTORS AFFECTING PERFORMANCE

As indicated in Figure 6-22, three zones are established when a consolidated illuminating composition is ignited and burns propagatively. In Zone A, essentially the burning surface, both exothermal and endothermal reactions take place resulting in the formation of gaseous fuel and oxidizer intermediates. These intermediates react exothermally in the flame zone. Usually, the pyro-

TABLE 6-4(A)
CHARACTERISTICS OF VARIOUS AIRCRAFT SIGNAL FLARES

Item	Method of actuation	Time lapse from actuation to full function, sec	Burning time, sec	Candlepower, 10^3	Fall, fps	Max L, in.	Max dia, in.	Weight, lb
SIGNAL ILLUMINATION, AIRCRAFT:	Fired from PISTOL, pyrotechnic, AN-M8 or PROJECTOR, pyrotechnic, hand, M9							
Double star:								
Red-red, AN-M37		5	10±3	25 (ea star)	Free	3.85	1.54	0.35
Red-red, AN-M37A1		....					1.57	
Red-red, AN-M37A2		5					1.57	
Yellow-yellow, AN-M38		....	10±3	12 (ea star)	Free	3.85	1.54	0.42
Yellow-yellow, AN-M38A1		....		20 (ea star)			1.57	0.35
Yellow-yellow, AN-M38A2		5		20 (ea star)			1.57	0.35
Green-green, AN-M39	Fired from PISTOL, pyrotechnic, AN-M8 or PROJECTOR, pyrotechnic, hand, M9	....	10±3	20 (ea star)	Free	3.85	1.54	0.35
Green-green, AN-M39A1		....					1.57	0.39
Green-green, AN-M39A2		5					1.57	0.39
Red-yellow, AN-M40		....	10±3	25 (R star) 12 (Y star)	Free	3.85	1.54	0.39
Red-yellow, AN-M40A1		....		25 (R star) 20 (Y star)			1.57	0.35
Red-yellow, AN-M40A2		5		25 (R star) 20 (Y star)			1.57	0.35
Red-green, AN-M41		....	10±3	25 (R star)	Free	3.85	1.54	0.35
Red-green, AN-M41A1		....		20 (G star)			1.57	0.39
Red-green, AN-M41A2		5					1.57	0.39
Single star:								
Red, AN-M43		....	10±3	25	Free	3.85	1.54	0.27
Red, AN-M43A1		....					1.57	
Red, AN-M43A2		5					1.57	
Yellow, AN-M44		0	10±3	15	Free	3.85	1.54	0.28
Yellow, AN-M44A1		....		25			1.57	
Yellow, AN-M44A2		5		25			1.57	
Green, AN-M45		....	10±3	30	Free	3.85	1.54	0.32
Green, AN-M45A1		....		25			1.57	
Green, AN-M45A2		5		25			1.57	
Tracer, double star:								
Yellow tracer, red-yellow star, AN-M53		....	....	....				
Yellow tracer, red-yellow star, AN-M53A1		0	T, 2.5 to 4 Star, 3 to 4.5	T, 30 R star, 48 Y star, 36	Free	3.85	1.57	0.40
Yellow tracer, red-yellow star, AN-M53A2		5	3 to 4.5	R star, 48 Y star, 36				
Green tracer, red-red star, AN-M54		....	....	....				
Green tracer, red-red star, AN-M54A1		0 5	T, 2.5 to 4 Star, 3 to 4.5 3 to	T, 25 Star, ea 48 Star, ea 48	Free	3.85	1.57	0.38
Green tracer, red-red star, AN-M54A2		5	3 to 4.5					
Green tracer, green-red star, AN-M55		....	....	....				
Green tracer, green-red star, AN-M55A1		0	T, 2.5 to 4 Star, 3 to 4.5	T, 25 G star, 20 R star, 48	Free	3.85	1.57	0.38
Green tracer, green-red star, AN-M55A2		5	3 to 4.5	G star, 20 R star, 48				

TABLE 6-4(A) (cont'd)

Item	Method of actuation	Time lapse from actuation to full function, sec	Burning time, sec	Candlepower, 10³	Fall, fps	Max L, in.	Max dia, in.	Weight, lb
Red tracer, green-green star, AN-M56 Red tracer, green-green star, AN-M56A1 Red tracer, green-green star, AN-M56A2	Fired from PISTOL, pyrotechnic, AN-M8 or PROJECTOR, pyrotechnic, hand, M9	...... 0 5	...... T, 2.5 to 4 Star, 3 to 4.5 3 to 4.5	...... T, 30 Star, ea 20 Star, ea 20	Free	3.85	1.57	0.38
Red tracer, red-red star, AN-M57 Red tracer, red-red star, AN-M57A1 Red tracer, red-red star, AN-M57A2		...... 0 5	.... 3 to 4.5	.... Star, ea 48	Free	3.85	1.57	0.39
Red tracer, green-red star, AN-M58 Red tracer, green-red star, AN-M58A1 Red tracer, green-red star, AN-M58A2		...... 0 5	.... 3 to 4.5	.... G star, 28 R star, 48	Free	3.85	1.57	0.39

technic composition is fuel rich and the excess fuel* reacts with oxygen from the atmosphere. Some of the energy required to form these gaseous intermediates results from the energy released in exothermic reactions on the burning surface (Zone A) and some from the flame zone. Energy from Zone A is also transferred to Zone B which may be considered the pre-ignition zone. Directly below Zone B is the remainder of the unreacted pyrotechnic composition, or Zone C.

Figure 6-23 shows a typical isothermal diagram of the temperature distribution of a pyrotechnic flame.[8] The temperature is not constant throughout the flame, the hottest portion occurring approximately two inches above the burning surface in the middle of the flame.

The flame produced by most pyrotechnic compositions is heterogeneous in nature, containing solid, liquid, and gaseous products of combustion. As most of the radiation produced is of thermal origin,[8] the distribution of radiation in any spectral region is determined, basically, by the chemical nature and physical state of the products which emit in that region and the temperature reached by these emitting species. The rate at which a pyrotechnic mixture burns depends on the amount and rate at which heat is evolved. Sufficient heat must be produced to raise the temperature of the ingredients to a point at which an exothermal reaction will be initiated, and the reaction rate must be sufficient to more than compensate for heat losses in order for the composition to burn propagatively. As are common to all combustion processes, the rate of burning, the products formed, and the flame temperature are affected markedly by the composition of the mixture, as well as by the physical condition of the materials and the ambient conditions under which it is burned. Some of the more important factors which affect the performance of light-producing pyrotechnic items include: (1) heat of reaction, (2) composition, (3) emitters, (4) color intensifiers, (5) binders, (6) particle size and distribution, (7) consolidation, (8) flare diameter, (9) case materials and coating, (10) temperature and pressure, (11) rotational spin, and (12) moisture. In addition to the above factors, the igniter or first fire used may also influence the output of a pyrotechnic device. Any changes in the pyrotechnic composition, the

* See example Paragraph 3-2.5.

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TABLE 6-4(B)
CHARACTERISTICS OF VARIOUS GROUND SIGNAL FLARES

Item	Method of actuation	Time lapse from actuation to full function, sec	Burning time, sec	Candlepower, 10^3	Fall, fps	Max L, in.	Max dia, lb	Weight, in.
SIGNAL, ILLUMINATION, GROUND:								
White star, cluster, M18A1 White star, cluster, M18A2		5.5	4 to 10	18 (for ea of 5 stars)	Free	10.14	1.88	1.09
Green star, cluster, M20A1 Green star, cluster, M20A2	Fired from LAUNCHER, grenade, M7 series	5.5	4 to 10	7 (for ea of 5 stars)	Free	10.14	1.88	1.09
Amber star, cluster, M22A1 Amber star, cluster, M22A2		5.5	4 to 10	2 (for ea of 5 stars)	Free	10.14	1.88	1.06
Red star, cluster, M52A1 Red star, cluster, M52A2		5.5	4 to 10	35 (for ea of 5 stars)	Free	10.14	1.88	1.09
Green star, cluster, M125 (T71)	Hand-held rocket-propelled launching mechanism	5.0	4 to 8	9 (for ea of 5 stars)	4.5	10.14	1.64	1.3
White star, parachute, M17A1 White star, parachute, M17A2	Fired from LAUNCHER, grenade, M7 series	5.5	20 to 30	20	7	10.40	1.88	1.04
Green star, parachute, M19A1 Green star, parachute, M19A2		5.5	20 to 30	20	7	10.40	1.88	1.02
Amber star, parachute, M21A1 Amber star, parachute, M21A2		5.5	20 to 30	4	7	10.40	1.88	1.00
Red star, parachute, M51A1 Red star, parachute, M51A2		5.5	20 to 30	20	7	10.40	1.88	1.02
Red star, parachute, M126 (T72)	Hand-held rocket-propelled type launching mechanism	5.0	50	5	8	9.64	1.64	....
White star, parachute, M127 (T73)			25	50	10–15	9.64	1.64	1.3
Red star, parachute, M131 (T66E1)			30	10	......	10.0	1.63	1.21

igniter, the container, etc.—which might be caused by storage conditions—may also markedly affect the output of light-producing pyrotechnics.

6-3.5.1 Heat of Reaction

One of the important factors in determining the luminous intensity of a light-producing pyrotechnic device is the temperature reached by the emitting species in the flame and produced by the burning of the pyrotechnic mixture. The temperature reached depends, in turn, on the amount and rate at which energy is released by the reaction. In general, therefore, the energy released during combustion should be high and products formed must be stable at the high temperatures necessary to produce the luminous intensity required for illuminating and signaling purposes.

The heats of reaction for the stoichiometric reaction between several oxidizers, and aluminum or magnesium as the fuel, are summarized in Tables 6-6 and 6-7. In general, for both fuels, the perchlorate oxidizers are the best solid energy producers on either a weight or volume basis; however, some of the nitrates are almost as good. Physical data and burning characteristics of stoichiometric mixtures of the alkali and alkaline-

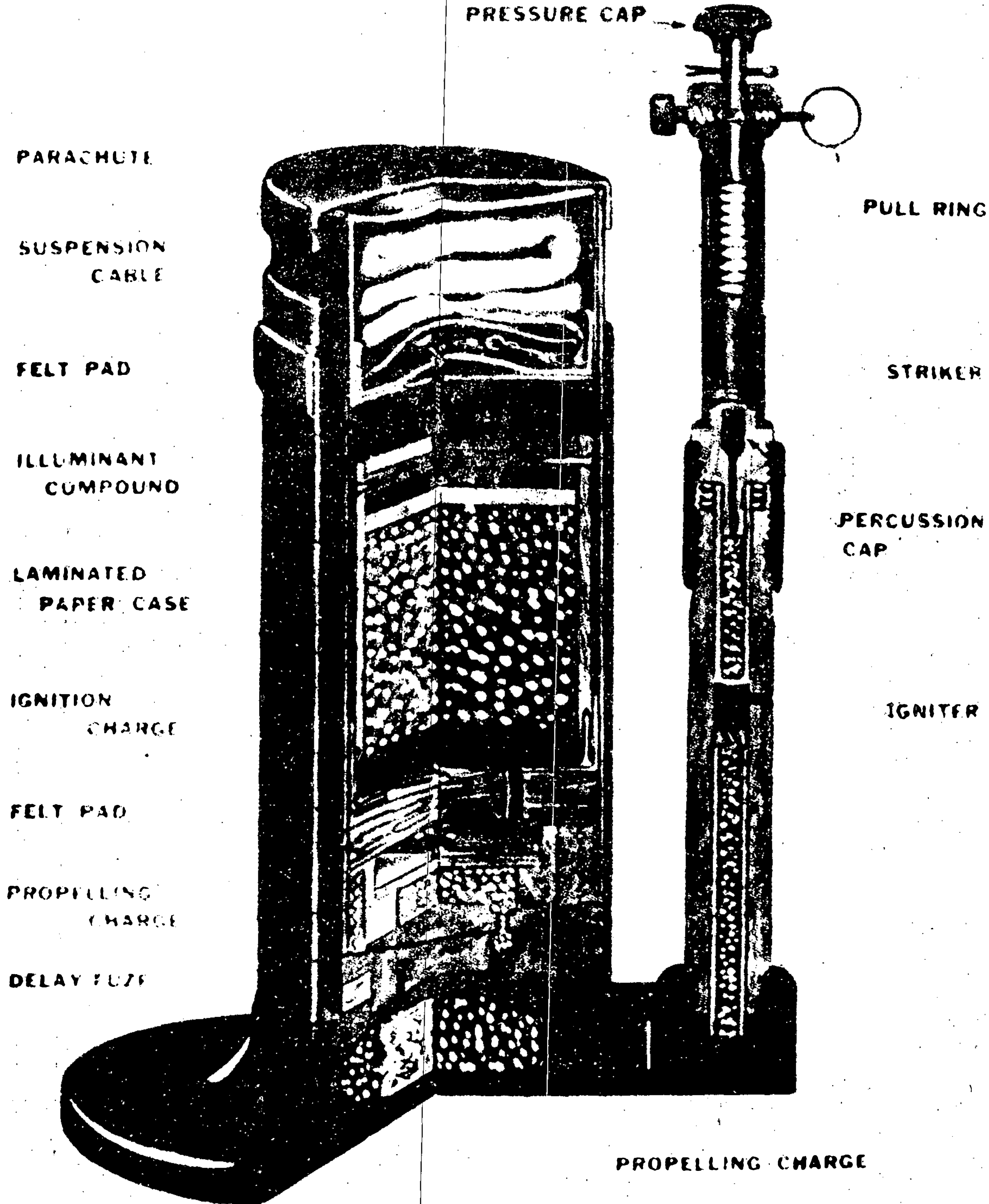

Figure 6-16. Typical Surface Trip Flare

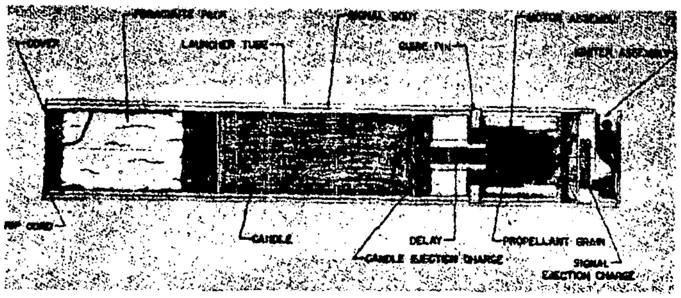

Figure 6-17. Typical Hand-Held Illuminating Signal

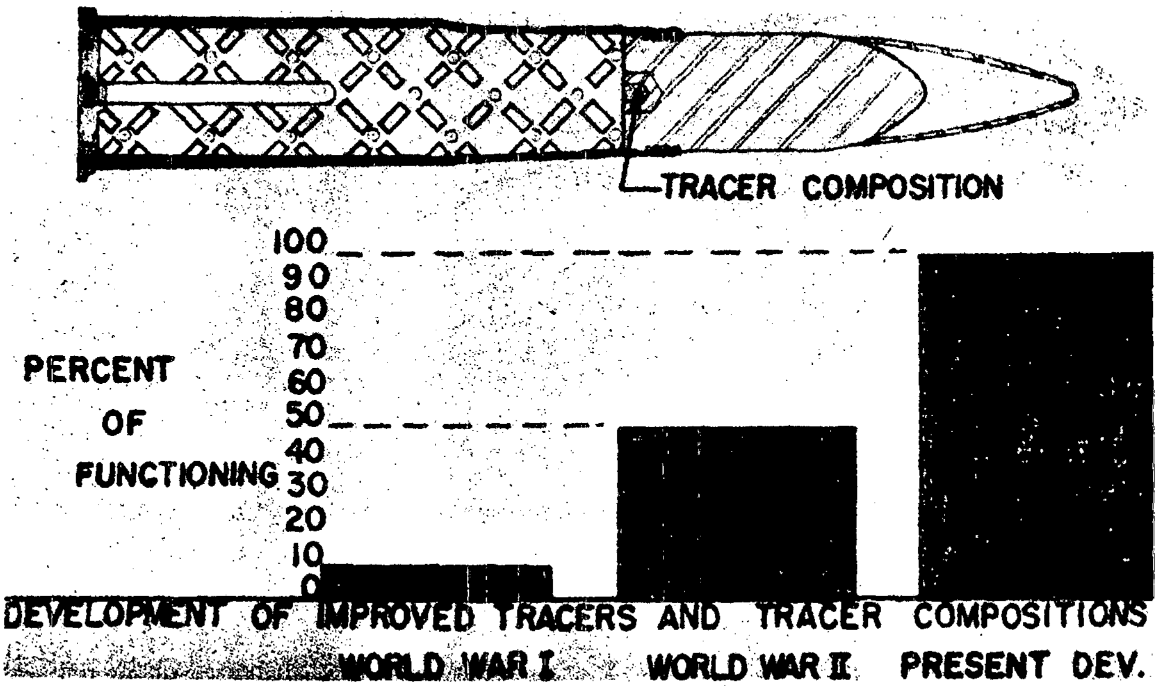

Figure 6-18. Small Arms Tracer

earth nitrates and potassium perchlorate are summarized in Table 6-8(A). The nitrates have been arranged in accordance with their molecular weight and the periodic group of the metallic element. It is evident from this arrangement that, in each group, as the molecular weight of the oxidant increases, the proportion of fuel in the stoichiometric mixture decreases. Consequently, the heat of reaction decreases. This is reflected in a decreasing luminous intensity, burnng rate, and efficiency. On this basis, it would appear that the lower molecular weight oxidants in each group should be preferred over those of higher molecular weight. Unfortunately, the lower weight oxidants tend to be extremely hygroscopic, which complicates their use in pyrotechnic compositions, and the shelf-life or the stability of mixtures containing them is markedly reduced in the presence of traces of atmospheric moisture. Greater care is therefore required in sealing the container and a higher probability exists for inadequate performance after long storage.

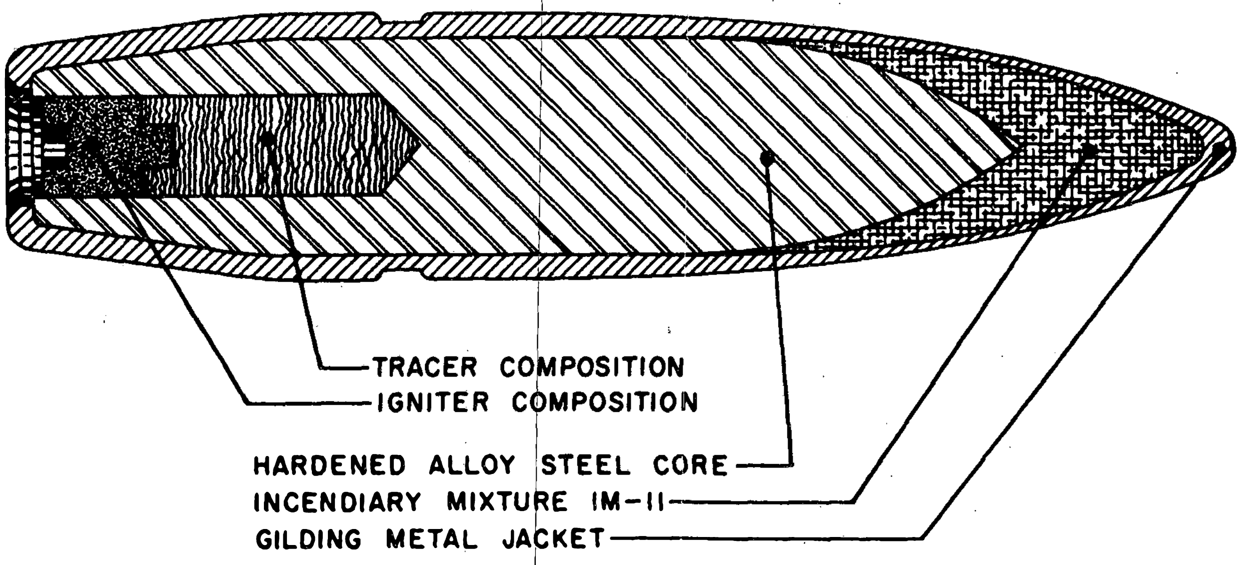

Figure 6-19. Armor-Piercing Tracer

6-3.5.2 Composition

The luminous intensities of flares containing binary mixtures of magnesium and the oxidizers listed in Table 6-8(B), change with increasing magnesium as shown in Figure 6-24. For a given oxidizer, the luminous intensity increases with the amount of magnesium until a maximum is reached at 70 to 80 percent magnesium. A further increase in the amount of magnesium results in a reduction in luminous intensity. The burning rate also is a maximum at 70 to 80 percent magnesium, as is illustrated in Figure 6-25.

As seen in Example 5, Paragraph 3-2.5, the amount of magnesium which will produce the maximum luminous intensity can be estimated if it is assumed that only that amount of magnesium, in excess of the stoichiometric amount, which can be vaporized by the stoichiometric reaction will react with the oxygen in the air. It requires about 1.5 kilocalories to vaporize one gram of magnesium; therefore, the amount of energy released by one gram of a stoichiometric mixture of magnesium and sodium nitrate will vaporize about 1.3 grams of magnesium. This corresponds to a mixture containing about 75 percent magnesium.

6-3.5.3 Emitters

As shown in Figure 6-24, the light intensity at the optimum magnesium content varies with the oxidizer used, ranging from about 10,000 candles per square inch for potassium nitrate to around 800,000 candles per square inch with sodium nitrate as the oxidizer. The difference is due to several factors, one of the more important of which is the metal in the oxidant. Sodium is a strong emitter in the visible region while potassium is not.

The elements used to color pyrotechnic flames for military uses are strontium, producing red; barium, producing green; and sodium, producing yellow. Copper (blue or green) has also been used.[22] Lithium (red), boron (green), thallium (green), rubidium (red), and cesium (blue), are also strong color producers, but their use is not practical because of cost, toxicity, or nature of their compounds.[36]

The chromaticity coordinates for a large number of yellow (sodium containing), green (barium containing), and red (strontium containing) flares, when plotted on a chromaticity diagram, form three straight lines which converge toward a common point, as shown in Figure 6-26.[37]

The dominant wavelength for the yellow flares (indicated by the intersection of the straight line with the perimeter of the chromaticity diagram) is around 590 millimicrons. Results of some yellow flares did not, as indicated in Figure 6-26, fall on the straight line. This is believed to be due

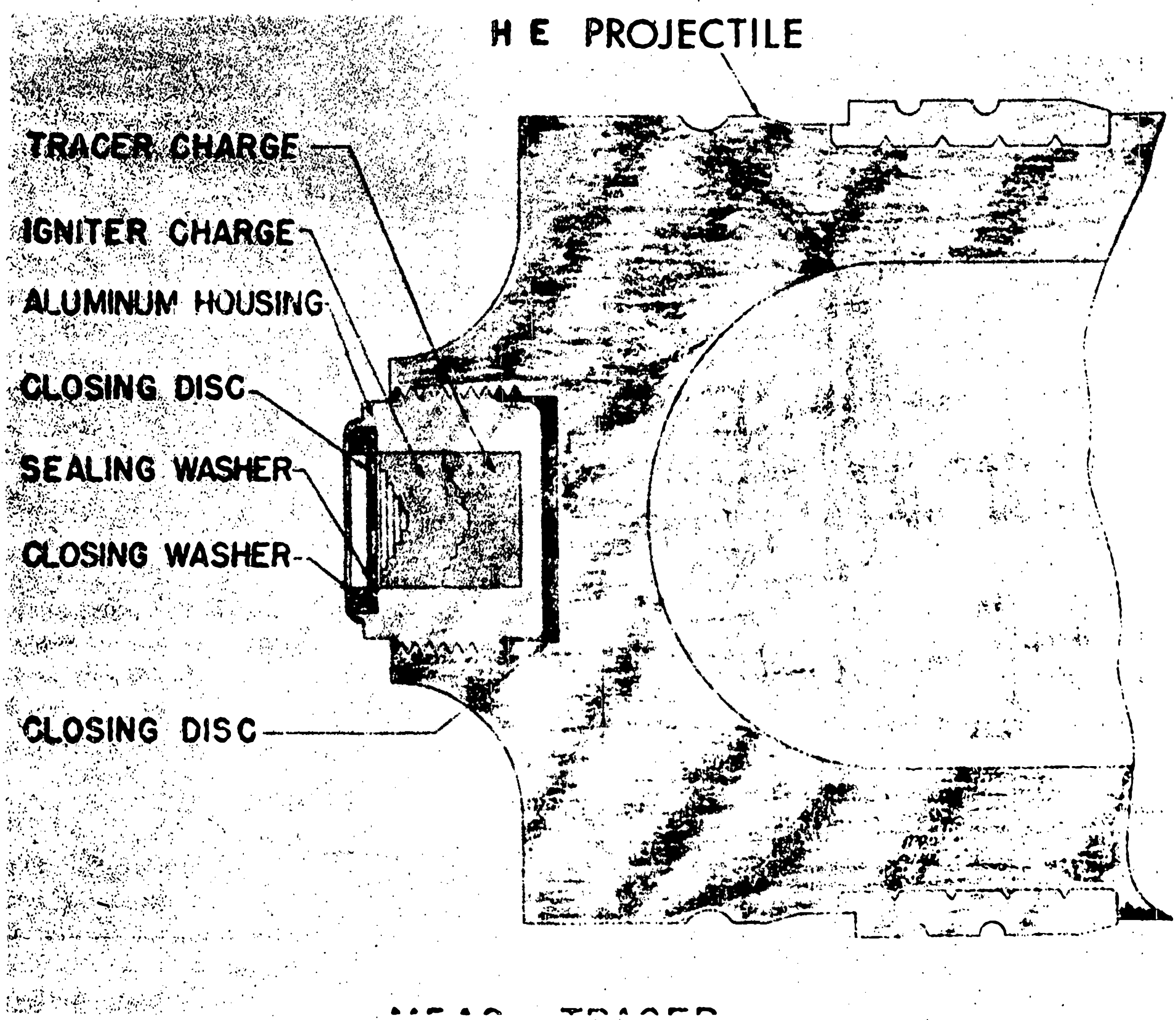

Figure 6-20. Artillery Tracer Element in Projectile

to measurement error as later measurements of flares with essentially the same composition fell close to the straight line. For the red flare and green flare, both of which contain a source of chlorine, the dominant wavelengths are approximately 640 millimicrons and approximately 524 millimicrons, respectively. Typical spectra obtained for a red, yellow, and green signal flare are given in Figure 6-27.

Spectroscopic studies indicate that most of the light produced by illumination and signal flares is due to a limited number of monatomic, diatomic, and possibly triatomic emitters which can exist at the high temperatures in a pyrotechnic flame.[35] Secondary emitters, including particulate matter, will influence the dominant wavelength, the colorimetric purity, the saturation, and the relative intensity of the light produced. These spectroscopic studies indicated that the red light produced by flares containing strontium and a source of chlorine is due to the diatomic molecule SrCl which emits strongly near 640 millimicrons. For flares which did not contain chlorine, but produce a red light, it was concluded that

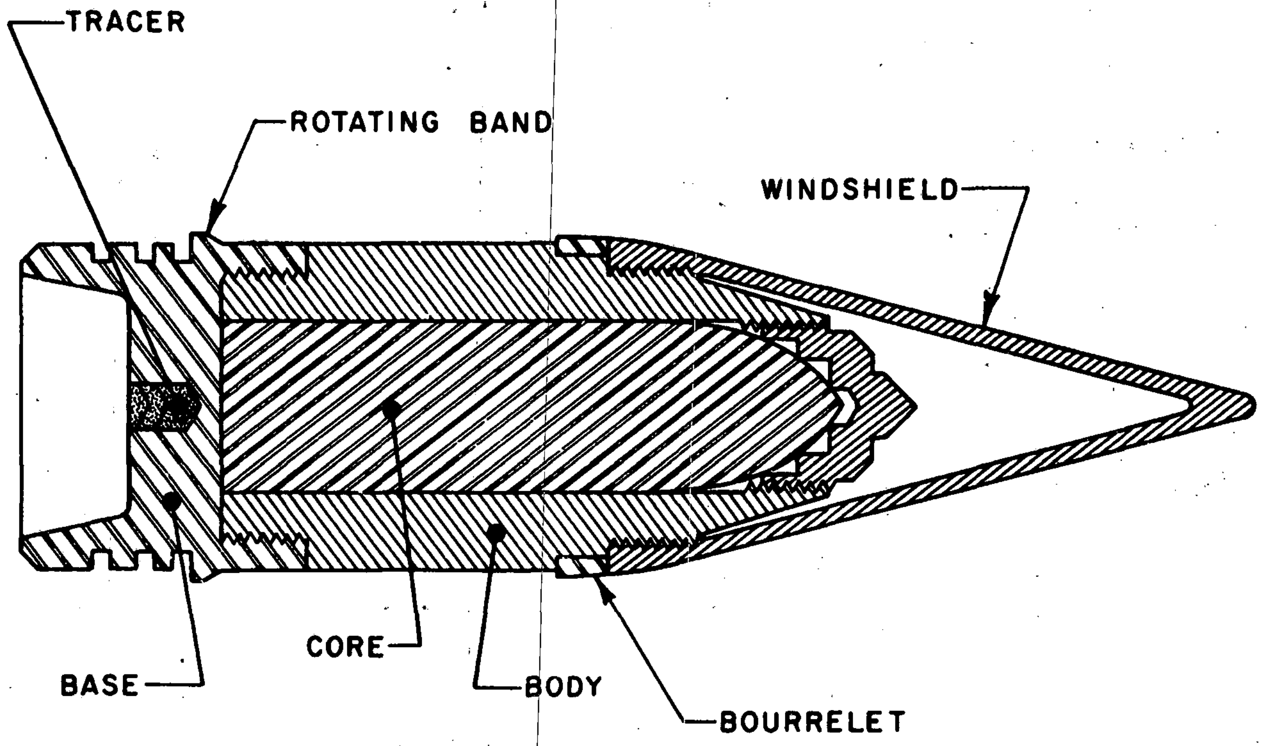

Figure 6-21. Artillery Tracer

the red light was, most likely, due to strontium oxide (SrO).

Green flames are produced by the band system of barium chloride ($BaCl$) in the 505- to 535-millimicron region of the spectrum. Most green flames show, in addition to the band emission from barium chloride, emission in the orange and red region, band emission from calcium chloride ($CaCl$) and strontium chloride ($SrCl$) formed from strontium and calcium impurities in the barium. In addition, there are contributions from an extensive barium oxide (BaO) band system (400 to 800 millimicrons).

Other studies indicate that the triatomic molecule $Sr(OH)$ (strong emission near 640 millimicrons) may contribute to the production of red light and that barium hydroxide $Ba(OH)$ (strong emission from 487 to 527 millimicrons) may contribute to the production of green light. There is some evidence that part of the radiation from the emitter may be due to chemiluminescence.[22]

Blue flames are normally produced by the emission of cuprous chloride ($CuCl$), much of which is radiated in the 420- to 460-millimicron region of the spectrum. The blue-green and green systems which are also produced are usually much weaker.

Yellow light is primarily due to the D lines of sodium and associated continuum. At high sodium concentrations, there is strong continuous emission in a region which extends from 500 to 700 millimicrons.

As shown in Figure 6-28, which is the spectral distribution of energy from a green flare,[39] the specific emission, approximately 525 millimicrons, is superimposed on a continuous background.[40] This results in a less saturated green. An increase in magnesium content, as shown in Figure 6-29 for a yellow flare,[37] results in a decreased saturation of the colored light produced. The continuous background may be due, in part, to incandescent carbon (from binder) as a binary mixture of magnesium and an oxidizer show somewhat less continuous background. It is also due, in part, in

TABLE 6-5
TYPICAL ILLUMINATING, SIGNALING, AND TRACER COMPOSITIONS

		FUEL			OXIDIZERS					Binder		
SOURCE	*COLOR*	*Magnesium*	*Aluminum*	*Misc.*	*Barium Nitrate*	*Sodium Oxalate*	*Sodium Nitrate*	*Strontium Nitrate*	*Misc.*	*Oil Linseed /Castor*	*Wax Paraffin*	*Misc.*
A	White	26.9			38.3				25.2(d)	2.9	6.7	
A	White	28.5	6.5		57.0						8.0	
A	White	36	4		43	12.5				1	2.5	
										1		
A	White	48			21	5	21			1	3	
										1		
C	Yellow	52					35					18(j)
C	Yellow	58					37					5(k)
												0.5(l)
C	Green	23			53							2(m)
												20(n)
												2(o)
C	Red	40						18	22(e)			6(n)
												7(o)
C			21		68	5				2		4(p)
D		58.0					37.5					4.5(s)
											(29)(k)	
B	Red	26.7						33.3	26.7(f)			6.7(q)
									5(g)			1.6(q)
B	Red	28						55				17(r)
B	Red	26						52				16(r)
D				90(a)								
				10(a)								
D	Dark			34(b)					28(h)			
									38(i)			
D	Dark			20(c)	50							15(t)
												5(u)

A. Naval Ammunition Depot, Crane, Indiana
B. Frankford Arsenal
C. Picatinny Arsenal
D. NOL White Oak, Maryland
a. Pyrotechnic compositions
b. Manganese
c. Silicon
d. Potassium Nitrate
e. Potassium Perchlorate
f. Strontium Peroxide
g. Strontium Oxalate
h. Barium Chromate
i. Lead Chromate
j. Thiokol
k. Laminac
l. Pluronic
m. Copper Powder
n. Hexachlorobenzene
o. Asphaltum
p. Sulphur
q. Calcium Resinate
r. Polyvinyl Chloride
s. Binder Composition
t. Zirconium Hydride
u. Tetranitrocarbazole

Note: **Details of preparation and material specifications should be obtained from source installations.**

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TABLE 6-6
HEATS OF REACTION OF ALUMINUM WITH STOICHIOMETRIC QUANTITIES OF VARIOUS OXIDANTS

Oxidant	*Composition Density, g/cc**	*Heat of Reaction*			*Products Assumed*
		Kcal, Total	*Cal/g Comp*	*Cal/cc Comp**	
$Al(ClO_4)_3$	2.70 est	1,603 est	2,960 est	7,990 est	Al_2O_3-$AlCl_3$
$Mg(ClO_4)_2$	2.64	3,230	2,930	7,750	Al_2O_3-$MgCl_2$
$LiClO_4$	2.53	1,590	2,970	7,520	Al_2O_3-$LiCl$
$Be(ClO_4)_2$	2.38 est	3,200 est	3,030 est	7,220 est	Al_2O_3-$BeCl_2$
$KClO_4$	2.58	1,598	2,530	6,540	Al_2O_3-KCl
$Be(NO_3)_2$	2.51 est	1,880 est	2,810 est	7,070 est	Al_2O_3-BeO-N_2
$Pb(NO_3)_2$	3.90	691	1,585	6,190	Al_2O_3-Pb-N_2
$NaNO_3$	2.39	1,624	2,080	4,980	Al_2O_3-Na_2O-N_2
F_2O(liq)	1.95	1,038	3,850	7,510	Al_2O_3-AlF_3
O_2(liq)	1.64	798	3,910	6,430	Al_2O_3
F_2(liq)	1.37	622	3,700	5,070	AlF_3
CuO	5.11	288	984	5,030	Al_2O_3-Cu
MeO_3	3.81	219	1,105	4,210	Al_2O_3 Me
Fe_2O_3	4.18	203	948	3,960	Al_2O_3-Fe
WO_3	5.46	198	693	3,780	Al_2O_3-W
V_2O_5	3.19	876	1,075	3,340	Al_2O_3-V
H_2O(liq)	1.46	194	1,800	2,620	Al_2O_3-H_2

* Based on calculated true density.

the visible, to the volume emission resulting from scattering by the solid particles of MgO which are essentially transparent in that environment.

White light can be produced by: (1) developing an extensive continuum, (2) exciting an extensive discrete band system, and (3) exciting two nearly complementary band systems. The light produced by incandescent carbon particles, or the extensive sodium continuum produced by the magnesium-sodium nitrate illuminating flare, are good examples of method (1). The extensive band system of barium oxide (BaO) (400 to 800 millimicrons) is an example of method (2). Suitable blending of the emission from strontium chloride (SrCl) (red), calcium chloride ($CaCl_2$) (yellow), and barium chloride ($BaCl_2$) (green) is an example of method (3).

6-3.5.4 Color Intensifiers

Highly chlorinated organic compounds such as hexachloroethane, hexachlorobenzene, polyvinylchloride, or Dechlorane are generally used as color intensifiers because they are a ready source of chlorine. As shown in Figure 6-30, the addition of increasing amounts of polyvinylchloride reduces the candlepower of a magnesium-strontium nitrate flare; however, its color value (see Paragraph 6-2.5.5) as a red flare increases as shown in Figure 6-31. Red color values of greater than 0.40 are impossible to obtain unless the color intensifier or binder is a chlorine containing compound. As already indicated, in the absence of a chlorine compound, the red color may be due to strontium oxide while, in the presence of chlorine, strontium chloride appears to be the emitting species.[35]

The production of a saturated green light by pyrotechnic means is more difficult than production of a red light of relatively high saturation. In most pyrotechnic items, the production of green light appears to depend on the green emitter, barium chloride, formed from the decomposition

TABLE 6-7
HEATS OF REACTION OF MAGNESIUM WITH STOICHIOMETRIC QUANTITIES OF VARIOUS OXIDANTS

Oxidant	*Composition Density, g/cc**	*Heat of Reaction*			*Products Assumed*
		Kcal, Total	*Cal/g Comp*	*Cal/cc Comp**	
$Al(ClO_4)_3$	2.14 est	1,732 est	2,810 est	6,010 est	MgO-$AlCl_3$
$Mg(ClO_4)_2$	2.11	1,163	2,785	5,880	MgO-$MgCl_2$
$LiClO_4$	2.04	573	2,810	5,740	MgO-$LiCl$
$NaClO_4$	2.10 est	581	2,650	5,560 est	MgO-$NaCl$
$KClO_4$	2.13	576	2,440	5,200	MgO-KCl
$Be(NO_3)_2$	2.04 est	681 est	2,675 est	5,420 est	MgO-BeO-N_2
$AgNO_3$	3.00	804	1,656	4,970	MgO-Ag-N_2
$LiNO_3$	2.03	631	2,430	4,940	MgO-Li_2O-N_2
$Pb(NO_3)_2$	3.03	756	1,584	4,800	MgO-Pb-N_2
$Ca(NO_3)_2$	2.04	647	2,265	4,620	MgO-CaO-N_2
$Sr(NO_3)_2$	2.38	627	1,880	4,480	MgO-SrO-N_2
$NaNO_3$	2.00	594	2,035	4,070	MgO-Na_2O-N_2
$Ba(NO_3)_2$	2.54	616	1,610	4,080	MgO-BaO-N_2
KNO_3	1.95	570	1,760	3,430	MgO-K_2O-N_2
F_2(liq)	1.29	264	4,230	5,460	MgF_2
O_2(liq)	1.44	288	3,570	5,140	MgO
PbO_2	5.37	222	770	4,140	MgO-Pb
BaO_2	3.53	137	630	2,220	MgO-Ba

* Based on calculated true density.

products of barium nitrate and an organic chlorine containing compound.

Magnesium also combines readily with chlorine and, therefore, will compete with the barium for the available chlorine. There is also competition between chlorine and oxygen for the barium. To select the best chlorine donor (Cl_2 is ideal but too difficult to handle), several compositions were tested which contained organic chlorides having different percentages of chlorine. These compounds lowered the candlepower, with generally improved color, and increased the amount of barium chloride formed. The best results were obtained with a composition containing 40 percent magnesium, 45 percent barium chlorate, 10 percent polyvinylidinechloride, and 5 percent Laminac. The chlorine-to-barium ratio was 3.48 to 1.0; the magnesium-to-barium ratio was 11.8 to 1.0, and the chlorine-(available to barium)-to-barium ratio was 0.272 to 1.0. All other chlorine containing additives improved the green color, but to a lesser degree. Ethylcellulose, the one nonchlorinated organic additive tested, improved the color of the flare slightly as a larger percentage of it was used. This slight improvement in color is believed to be due to the decrease in luminous intensity. The improvement in color of the compositions containing chlorinated organic additives resulted from an increase in the amount of barium chloride formed as well as from decreased luminous output.

It has also been suggested that the addition of a chlorine containing compound to a flare mixture may, by shift of equilibrium, result in the formation of barium hydroxide which emits strongly in the green.[22]

6-3.5.5 Binders

Binding agents—including certain resins, waxes, plastics, and oils—serve multiple purposes in pyrotechnic compositions. They are added to

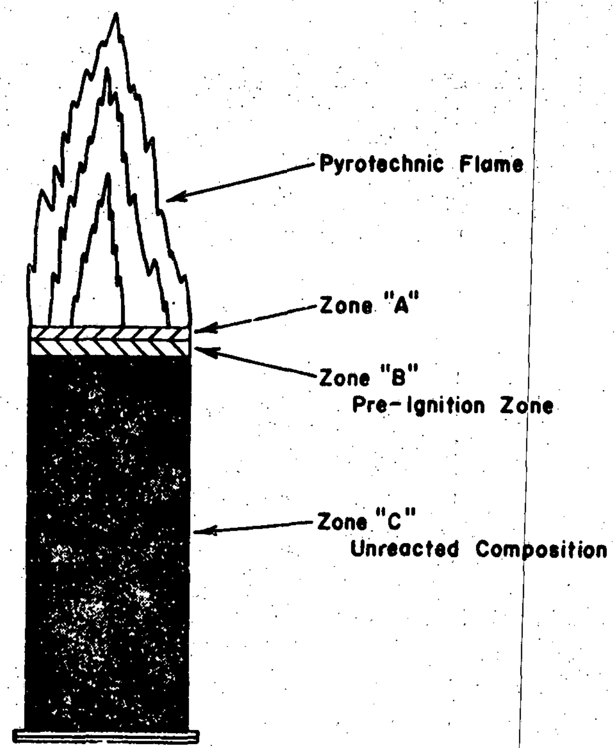

Figure 6-22. Zones in Flame Propagation

prevent segregation and to obtain more uniformly blended compositions. In addition, they serve to make the finely divided particles of metal and oxidizer adhere to each other and help to obtain maximum density and, therefore, efficiency in burning. Binders also frequently desensitize mixtures which would otherwise be very sensitive to impact, friction, and static electricity and, as binder content is increased, burning rate is decreased and candlepower reduced.

Materials such as linseed oil, used earlier in most standard pyrotechnic compositions as binders, oxidized and hardened during storage causing a change in the burning characteristics. The replacement of linseed oil by Laminac, a polyester resin,[41] greatly reduced this problem.[8] It was found that self-hardening polyester resins tended to minimize the need for high consolidation pressures. Most of the polyester resins used are essentially esters manufactured from glycols and unsaturated acids, and monomeric cross-linking additives such as styrene and diallyl phthalate which are utilized to cure the resin. When the resins are catalyzed, they undergo a transition from liquid gel to solid as they cure.[42]

The results of a series of tests involving polyester resins, presented in Table 6-9, led to the conclusion that the majority of these resins would be satisfactory and that mixtures containing these materials would be as stable and have the same burning characteristics as mixtures containing Laminac as a binding agent.

The luminous intensity for all mixtures tested, including a binary mixture not containing a binder of any kind, varied greatly during the first month of storage. This strongly indicates that the binder is not the cause of this variation. There is, however, little, if any, change in burning rate associated with this change in luminous intensity.

6-3.5.6 Particle Size

The rate of reaction of a pyrotechnic composition is related to the specific surface of the ingredients. Factors such as size, shape, distribution, and surface of the particles affect the properties of the particulate material and must be accurately controlled. These factors affect the packing properties of the ingredients which, in turn, affect the weight-volume relationship of the particles.

As has been indicated in the discussion of propagative burning (Paragraph 3-3.6), the burning rate and candlepower of a pyrotechnic composition depend on the particle size of the metal powder fuel. This effect is shown in Figures 6-32(A) and 6-32(B), and Table 6-10 for an illuminant mixture containing magnesium, sodium nitrate, polyvinylchloride, and Laminac. A decrease in particle size for the spherical particles results in an increase in the specific surface—the surface area associated with one gram of powder—an increase in the candlepower, and an increase in the burning rate. This is in agreement with the theory presented in Paragraph 3-3.6.

The above results were obtained for compositions in which the magnesium was essentially a sphere; any other particle shape will result in a larger specific surface than that of a comparable sphere. In Table 6-11, the burning characteristics of similar compositions prepared with ground and with atomized magnesium having the same sieve

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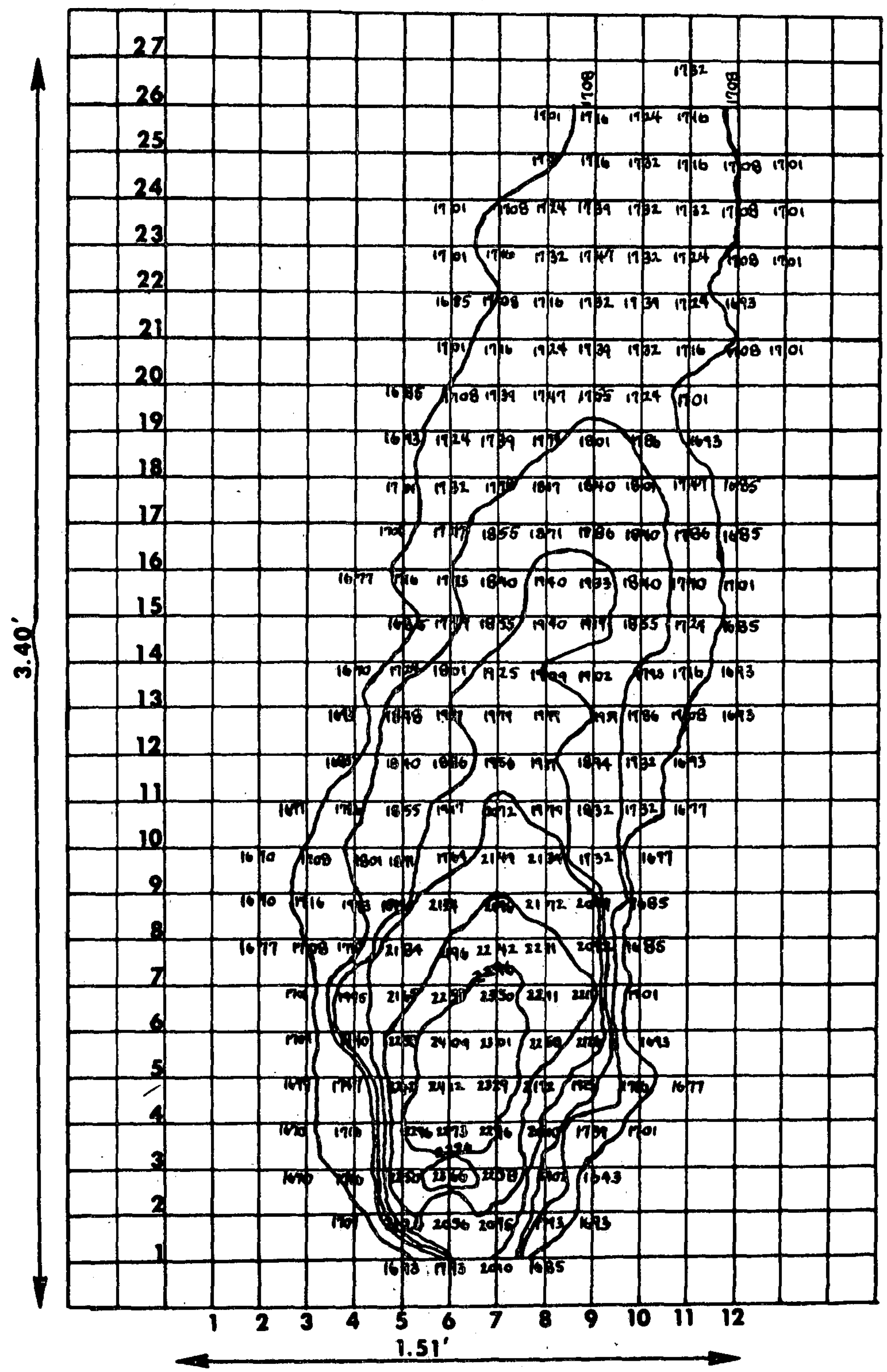

Figure 6-23. Temperature Distribution in a Pyrotechnic Flame

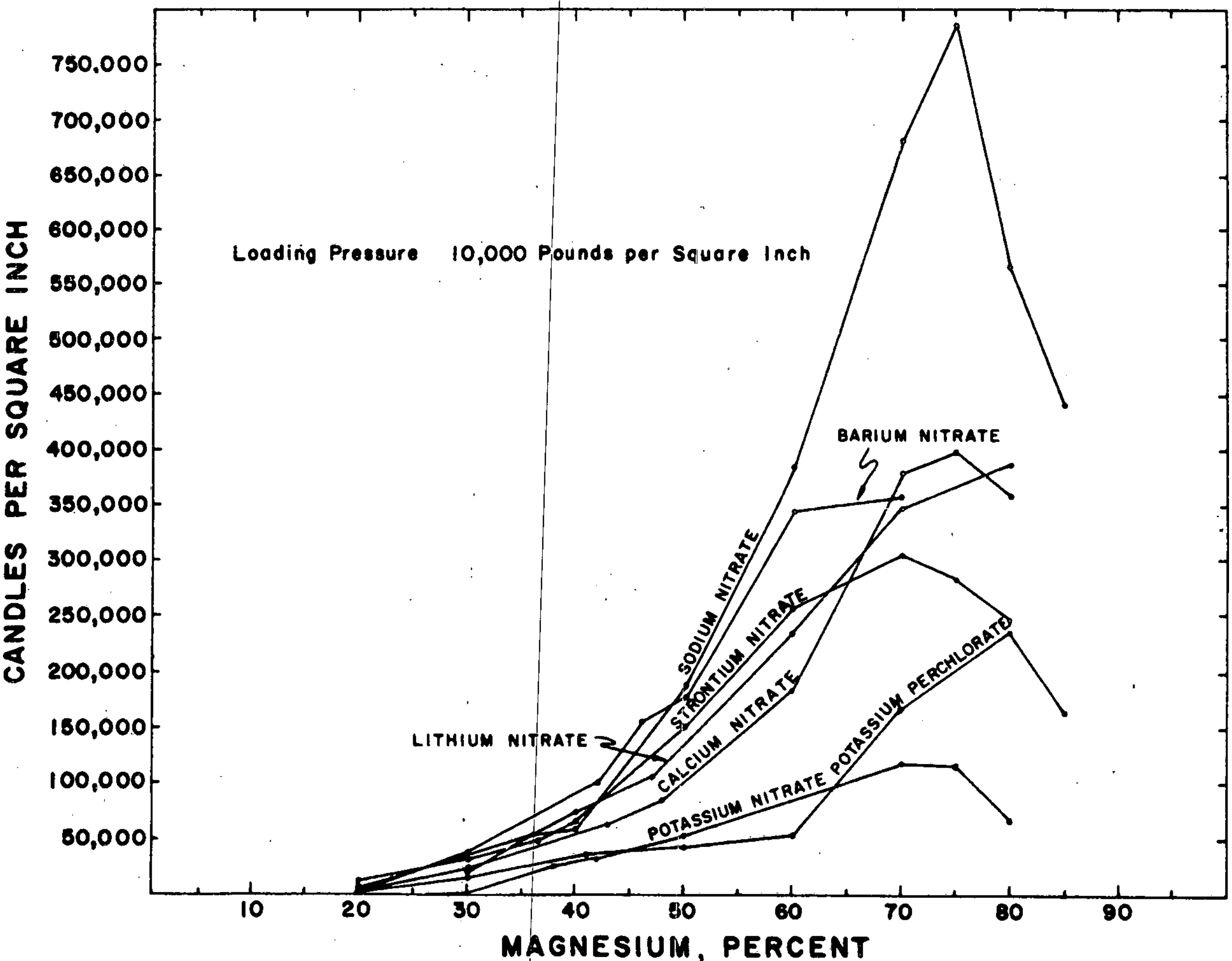

Figure 6-24. Luminous Intensity as a Function of Magnesium Content of Binary Mixtures Containing Various Oxidizing Agents

sizes are compared.[48] The ground magnesium (which for some sieve sizes will have the greater specific surface) gives a higher luminous intensity and a faster burning rate. An increase in burning rate and luminous intensity generally follows the increase of specific surface of the ingredients. It is to be noted, however, that an increase in burning rate and luminous intensity may be accompanied by a reduction in the overall efficiency.

The burning characteristics of pyrotechnic compositions are also affected by the specific surface of the oxidizers and other ingredients. While relatively little data are available on the specific effect produced in a particular system, it is important that they be considered.

6-3.5.7 Consolidation[44]

The degree of consolidation (loading pressure) has a varying effect on the burning rate and luminous intensity of a pyrotechnic mixture, depending on the physical characteristics of the components. Increased consolidation pressure results in an increased pellet density which approaches a maximum, which is usually five to ten percent less than the theoretical value. In Figure 6-33 and Table 6-12 are shown the effects of loading pressure on burning rate, luminous intensity, and other characteristics, between 2000 psi and 25,000 psi for magnesium-sodium nitrate flares. The linear burning rate shows a slight decrease with loading pressure while the mass burning rate and lum-

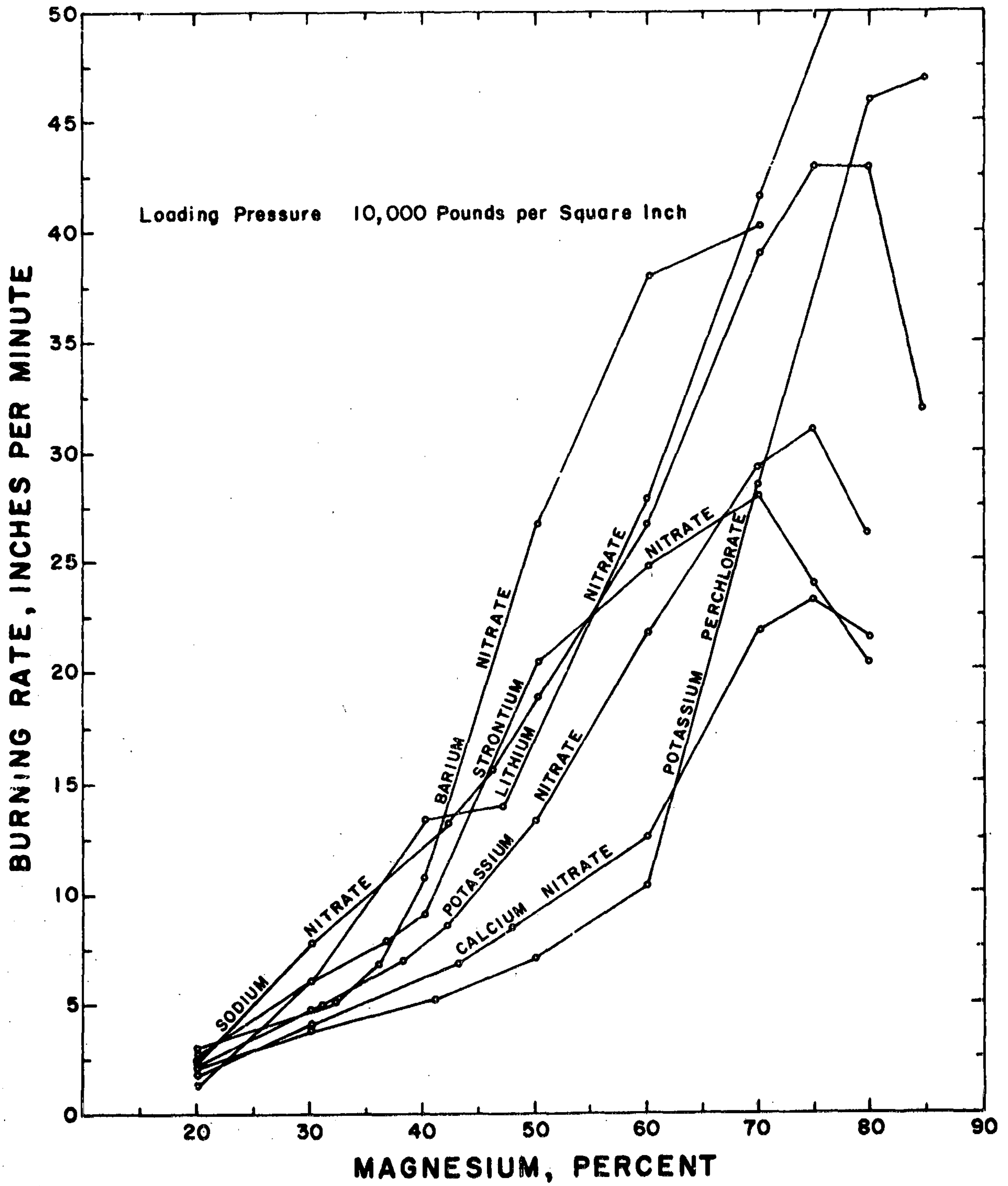

Figure 6-25. Burning Rate as a Function of Magnesium Content of Binary Mixtures Containing Various Oxidizing Agents

TABLE 6-8(A)
PHYSICAL DATA AND BURNING CHARACTERISTICS FOR STOICHIOMETRIC MIXTURES OF VARIOUS OXIDANTS WITH ATOMIZED MAGNESIUM

Oxidant	*Stoichio-metric Ratio*	*Calculated Heat of Reaction Kcal*	*Cal/g*	*Luminous Intensity Candle/sq in.*	*Burning Rate, in./min*	*Efficiency, candle-sec/g*
$LiNO_3$	53.2/46.8	631.0	2430	109,000	13.9	17,500
$NaNO_3$	58.3/41.7	595.4	2060	102,000	13.1	15,500
KNO_3	62.5/37.5	569.8	1760	27,500	6.9	8,000
$Ca(NO_3)_2$	57.5/42.5	647.1	2260	64,000	6.8	18,000
$Sr(NO_3)_2$	63.5/36.5	626.8	1881	50,500	7.7	12,500
$Ba(NO_3)_2$	68.8/31.8	615.5	1606	45,000	5.1	14,000
$KClO_4$	58.8/41.2	515.8	2441	37,000	5.2	15,000

inous intensity show an increasing trend. These data have been found consistent with the trends observed in most pyrotechnic compositions containing magnesium although they are not as consistent for compositions containing aluminum.

Insufficient consolidation of tracer composition in the tracer cavity may result in the tracer malfunction known as "blow out," where the pyrotechnic composition is ejected from its cavity. This usually happens shortly after the projectile leaves the gun. In ammunition depending on tracer functioning for self-destruction, this usually results in a premature projectile functioning.

The required loading pressure or extent of consolidation depends on the setback forces and amount of rough handling to which the item is to be subjected. Generally, the greater the setback forces, the greater the required loading pressure.

6-3.5.8 Flare Diameter

The influence of flare diameter on the linear and mass burning rate, luminous intensity, temperature distribution, color value, luminous efficiency, and flame geometry may vary considerably depending on general configuration of the system and the pyrotechnic composition. A basic end-burning flare, free from the influences of case geometry and composition and associated materials, should possess a linear burning rate essentially independent of the flare diameter. This has been the case in many investigations conducted over rather limited diameter ranges; however, in other cases the results have varied considerably. With certain compositions, investigators have observed an apparent maximum in linear burning rate associated with a particular flare diameter.[45]

Investigations of typical yellow, green, and red flare compositions with diameters varying between 0.6 inch to 1.1 inches indicated that the luminous intensity could be expressed mathematically by an equation of the form:[46]

$$y = ax^n \qquad (6\text{-}15)$$

(for diameters less than approximately 4 in.) where y is the luminous intensity (candela), a is a constant, x is the flare diameter in inches, and n is a constant. The value of n, which was obtained when the results were plotted on log-log paper, indicated that n is slightly greater than 2.0 which may be due to some change in the flame geometry, or to an increase in the flame temperature. The flame area tended to exhibit a direct proportionality with the square of the flare diameter. Yellow and green flares showed an increase in luminous efficiency with increased luminous intensity; however, their flames appeared to become less saturated with increasing flare diameter. Red flares exhibited maximum luminous efficiencies for intermediate values of luminous intensity and the color characteristics did not appear to change with an increase in flare diameter.

6-3.5.9 Case Materials and Coating

Both the physical and chemical characteristics of pyrotechnic case material and associated coat-

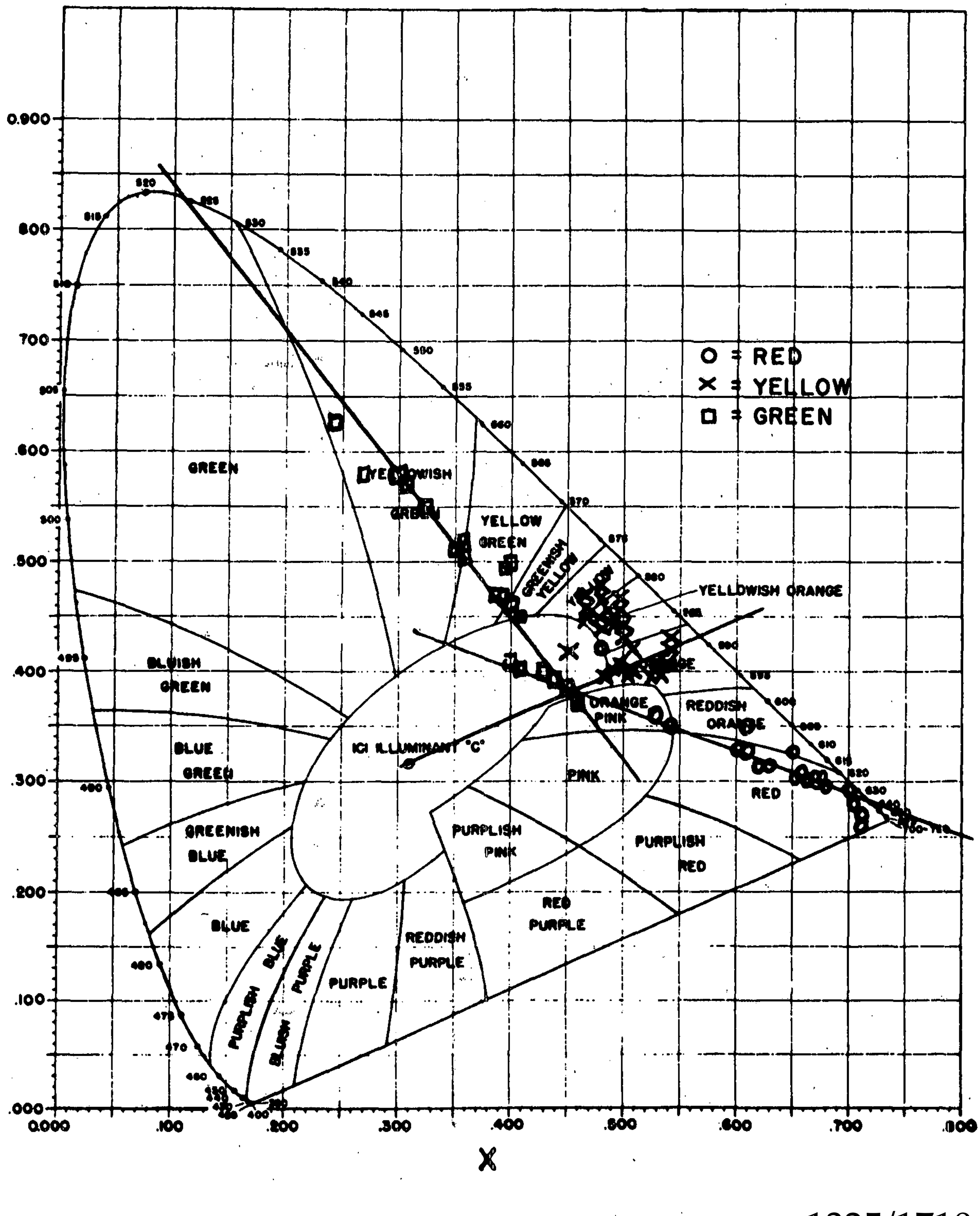

Figure 6-26. Chromaticity Data for Red, Yellow, and Green Flares

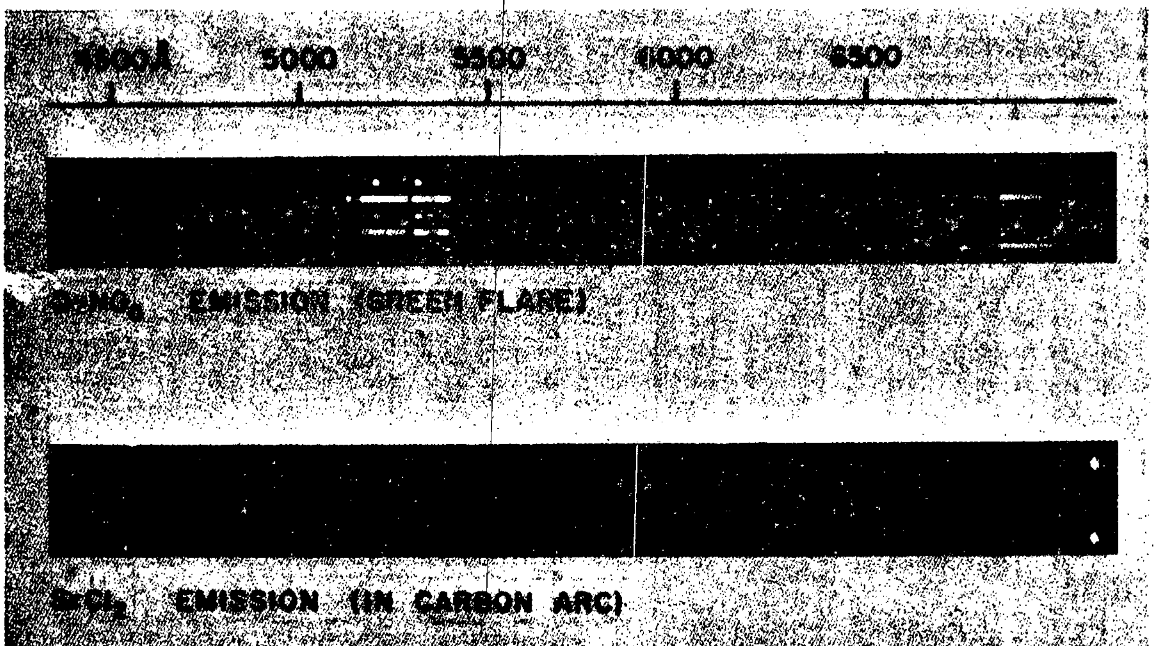

Figure 6-27. Typical Spectra of Signal Flares

ing may affect the burning characteristics and luminous output of flares. Steel cases with high thermal conductivities, as compared to those constructed of paper or other materials, may preheat the composition and thus tend to decrease the time to ignition and increase the burning rate. In addition, the increased wall temperature may affect the coating material and promote side burning. Both of these conditions tend to increase the luminous intensity; however, they can cause unpredictable performance.

In studies of colored flare illuminating compositions,[47] it was found that red and yellow flares had higher burning rates and luminous intensities when using steel cases as opposed to paper cases. When paper-lined steel cases were used, luminous intensity values were midway between those for steel and those for paper, although burning rates were comparable to those obtained for paper cases. In contrast, the relatively cooler-burning green composition gave lower luminous intensity values in the steel case than in the paper case (for which intermediate values were obtained) even though the burning rates remained essentially the same. In this case, the heat loss to the surroundings from the steel case may more than compensate for the increase observed with red and yellow flare compositions. Some compositions also have been observed to burn more rapidly and produce a greater luminous intensity in laminated plastic cases than when loaded into paper cases. In this case, the character of the adherence of the composition to the wall may be important; however, a completely satisfactory explanation is difficult.

6-3.5.10 Temperature and Pressure

Ambient pressure and temperature have been found to have varying effects on the operating characteristics of illuminating flares, depending on the composition. In a study[48] made on yellow, red, and green compositions it was found that at a reduced temperature, $-65°F$, the candlepower and burning time of the flares, except for green, decreased. The color value was found to be affected differently, depending on the composition at this temperature. (See Tables 6-13, 6-14, and 6-15.) At high simulated altitudes, the burning time increased while the candlepower decreased for most flares tested in this study. Color values were increased at the higher simulated altitudes with the

TABLE 6-8(B)
CHARACTERISTICS OF BINARY MIXTURES CONTAINING OXIDIZING AGENTS AND ATOMIZED MAGNESIUM, GRADE A

Composition* Parts by Weight: Sodium Nitrate	Atom. Gr. A (125μ) magnesium	Horizontal Luminous Intensity, Candles per Square Inch	Burning Rate, in./min	Yellow Color Value	Ignition Temperature °N	Ignitibility As Black Powder, g	Impact Test B.W. App.,† cm	Pendulum Friction Test Reaction with: Steel Shoe	Fiber Shoe	120°C Vacuum Stability Test, cc, gas/40 hrs.	Density gas/cc	Efficiency, Candle-Seconds per gram
80	20	4,500	2.4	—	635	>5	85	None	—	0.30	1.91	3,600
70	30	38,500	7.7	—	630	>5	95	None	—	0.35	1.87	9,700
58	42	102,000	13.1	0.025	630	0.5	100+	None	—	0.32	1.82	15,500
54	46	155,000	15.6	0.024	635	0.5	100+	None	—	0.31	1.79	20,000
50	50	180,000	16.5	0.026	635	1.25	100	None	—	0.36	1.74	20,000
40	60	388,000	26.7	0.029	620	1.25	100	None	—	0.32	1.71	31,000
30	70	685,000	39	0.036	620	1.75	100	None	—	0.32	1.65	35,000
25	75	785,000	43	0.033	—	>5	100+	None	—	—	1.62	41,000
20	80	570,000	43	0.038	570	2.75	100+	None	—	0.33	1.59	30,000
15	85	445,000	32	0.041	570	>5	100+	None	—	0.23	1.51	33,000
Barium Nitrate	Atom.Gr.A Magnesium											
80	20	6,500	2.9	pale green	680	>5	100+	None	—	0.25	2.48	3,300
68	32	45,000	5.1	pale green	670	>5	100+	None	—	0.25	2.24	14,000
64	36	53,000	6.7	palo green	640	>5	100+	None	—	0.15	2.21	13,000
60	40	59,500	10.7	pale green	635	>5	100+	None	—	0.18	2.08	9,800
50	50	156,000	16.8	pale green	615	1.25	100+	None	—	0.21	1.96	13,000
40	60	348,000	38.1	pale green	625	1.25	100+	None	—	0.16	1.86	17,500
30	70	360,000	40.3	pale green	615	>5	100+	None	—	0.20	1.84	17,500
20	80	Erratic Burning		—	625	>5	100+	None	—	0.22	1.83	—
Strontium Nitrate	Atom.Gr.A Magnesium			Red Color Value								
80	20	10,500	2.7	0.20	615	>5	100+	None	—	0.13	2.32	6,500
70	30	34,000	6.0	0.19	600	>5	100±	None	—	0.16	2.05	10,000
63.5	36.5	50,500	7.7	0.18	600	>5	100+	None	—	0.15	1.95	12,500
60	40	68,500	8.9	0.16	600	>5	100+	None	—	0.14	1.92	12,000
50	50	152,000	21.1	0.22	610	>5	90	None	—	0.14	1.79	14,500
40	60	260,500	24.8	0.24	610	>5	100	None	—	0.19	1.72	22,000
30	70	307,000	28.0	0.26	615	>5	100+	None	—	0.27	1.63	24,000
25	75	286,000	24.0	0.31	620	>5	100+	None	—	0.18	1.57	27,500
20	80	250,000	20.4	0.27	610	>5	100+	None	—	—	1.52	33,000
Lithium Nitrate	Atom.Gr.A Magnesium			Red Color Value								
80	20	Erratic Burning									1.98	—
70	30	21,000	6.01	0.17							1.77	7,200
60	40	78,500	13.3	0.16							1.68	12,500
53	47	109,000	13.9	0.18							1.62	17,500
40	60	236,000	27.9	0.20							1.54	20,000
30	70	350,000	41.6	0.21							1.49	20,000
20	80	370,000	45.1	0.20							1.43	22,000
Calcium Nitrate	Atom.Gr.A Magnesium			Red Color Value								
80	20	3,500	1.8	0.22							1.99	3,500
70	30	25,000	4.0	0.16							1.96	11,500
57	43	64,000	6.8	0.16							1.86	18,500
52	48	86,000	8.4	0.18							1.81	20,000
40	60	188,000	12.5	0.25							1.73	32,000
30	70	382,000	23.0	0.28							1.56	40,000
25	75	400,000	23.3	0.29							1.51	41,000
20	80	362,000	21.5	0.30							1.50	41,000
Potassium Nitrate	Atom.Gr.A Magnesium											
80	20	900	2.3	White	660	>5	80	None	—	0.16	1.81	600
70	30	1,100	4.7	White	650	2.75	80	None	—	0.13	3.75	800
62	38	27,500	6.9	White	660	1.5	90	None	—	0.15	1.73	8,400
58	42	36,000	8.5	White	655	2	75	None	—	0.11	1.72	9,000
50	50	55,000	13.3	White	650	1.75	90	None	—	0.15	1.68	9,000
40	60	86,000	21.3	White	645	1.75	90	None	—	0.13	1.63	9,000
30	70	119,000	29.3	White	635	1.5	100	None	—	0.13	1.56	9,500
25	75	116,000	31.1	White	—	4	100+	None	—	0.19	1.53	9,000
20	80	70,000	26.4	White	630	>5	100+	None	—	0.18	1.53	6,300
Potassium Perchlorate	Atom.Gr.A Magnesium											
80	20	2,500	2.2	White	700	>5	100+	None	—	0.30	1.91	3,100
70	30	17,500	3.8	White	710	>5	100+	None	—	0.24	1.78	9,500
59	41	37,000	5.2	White	705	>5	100+	None	—	0.28	1.72	15,000
50	50	45,000	7.0	White	715	>5	100+	None	—	0.25	1.66	14,000
40	60	54,000	10.3	White	700	>5	100+	None	—	0.26	1.60	12,000
30	70	171,000	26.5	White	700		100+	None	—	0.35	1.54	14,500
20	80	240,000	46	White	—		100+	None	—	0.22	1.51	12,500
15	85	167,000	47	White	—		100+	None	—	—	1.50	8,500

*Loading Pressure 10,000 psi in 1.4 Square Inch Candle Cases.
†Bureau of Mines Apparatus.

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TABLE 6-9
CHARACTERISTICS OF PYROTECHNIC COMPOSITIONS CONTAINING VARIOUS POLYESTER RESIN BINDERS

Polyester Resins	*Candlepower, 1000 Candles*	*Burning Rate, inch/minute*	*Total Integral Light, 10^6 Candle-seconds*	*CIE Coordinates*	
				x	*y*
Hetron-92	84.0	4.4	3.7	0.52	0.35
Paraplex-43	70.3	3.5	4.0	0.54	0.35
Paraplex-444	65.0	4.2	3.2	0.50	0.35
Laminac 4116	64.5	3.8	3.3	0.51	0.36
Paraplex-13	62.5	3.3	3.7	0.53	0.35
Paraplex-47	62.0	3.4	3.5	0.52	0.36
Glidpol-1001-A	61.2	3.5	3.4	0.52	0.35
Interchemical-401	60.5	3.9	3.5	0.57	0.32
Pleogen-1150	60.3	4.0	3.2	0.54	0.34
Aropol-7120	60.0	3.8	3.5	0.56	0.33
Polylite-8001	59.3	4.1	3.3	0.56	0.33
Interchemical-937	58.0	4.0	3.3	0.57	0.33
Polylite-8007	56.8	3.8	3.2	0.55	0.34
4116-85%:4134-15%	56.6	4.1	3.2	0.55	0.33
Aropol-7300	56.4	4.3	3.0	0.56	0.33
Pleogen-1006	56.4	4.1	3.0	0.55	0.34
ED-199	56.2	4.1	3.2	0.57	0.32
PLL-4262	56.0	4.1	3.1	0.58	0.32
Vibrin-1088-B	54.5	3.4	3.4	0.56	0.33
Paraplex-49	54.4	3.4	3.1	0.52	0.35
Laminac-4134	53.7	3.9	3.0	0.55	0.34
Vibrin-117	52.9	3.9	3.0	0.55	0.33
Interchemical-312	51.7	4.1	2.9	0.56	0.32
Celanese-MX-314	51.4	4.0	2.8	0.55	0.34
Interchemical-1191	51.4	4.0	2.9	0.56	0.33
Interchemical-730	51.4	3.7	3.1	0.57	0.32
Interchemical-1154	50.2	4.0	2.9	0.56	0.33
Stypol-4051	49.5	3.8	2.8	0.55	0.33
Stypol-405	49.1	4.0	2.7	0.55	0.34
Aropol-7110	49.0	4.2	2.7	0.56	0.33
Selectron-5027	48.4	3.7	2.9	0.55	0.34
Celanese MR 28-C	46.0	4.0	2.6	0.55	0.34
Epoxy Resin					
Bakelite ERL-2795	81.2	5.1	3.8	0.59	0.30

exception of green which remained essentially constant.

The range of altitudes at which pyrotechnic items may be used is from zero to approximately 250,000 feet. The effects produced under reduced pressures can be attributed to both the reduction in oxygen and ambient pressure. The effects of oxygen reduction may be greater when fuel-rich mixtures are burned. For stoichiometric or near-stoichiometric compositions, the effect is mainly that of pressure. It has been shown that by maintaining a pressure over the flare surface through partial confinement by use of a nozzle, the burning rate at high simulated altitude could be raised to the same level as that at sea level.[49]

Larger flame plumes are produced as the ambient pressure is reduced due to the decrease in resistance offered by the air molecules. Intermediate reactions occur further away from the flare surface and, in many cases, a "dark zone" can be observed just above the flare surface and initial reaction zones. If the pressure becomes low enough, a point will be reached where the reaction will not be self-sustaining.

The inverse relationship between candlepower and color value is attributed to the increasing importance of the color line and band emission from excited atoms and molecules at the higher altitudes.

6-3.5.11 Rotational Spin

The effect of rotational spin on the burning characteristics of compositions has been investigated. It has been found that the rotational spin

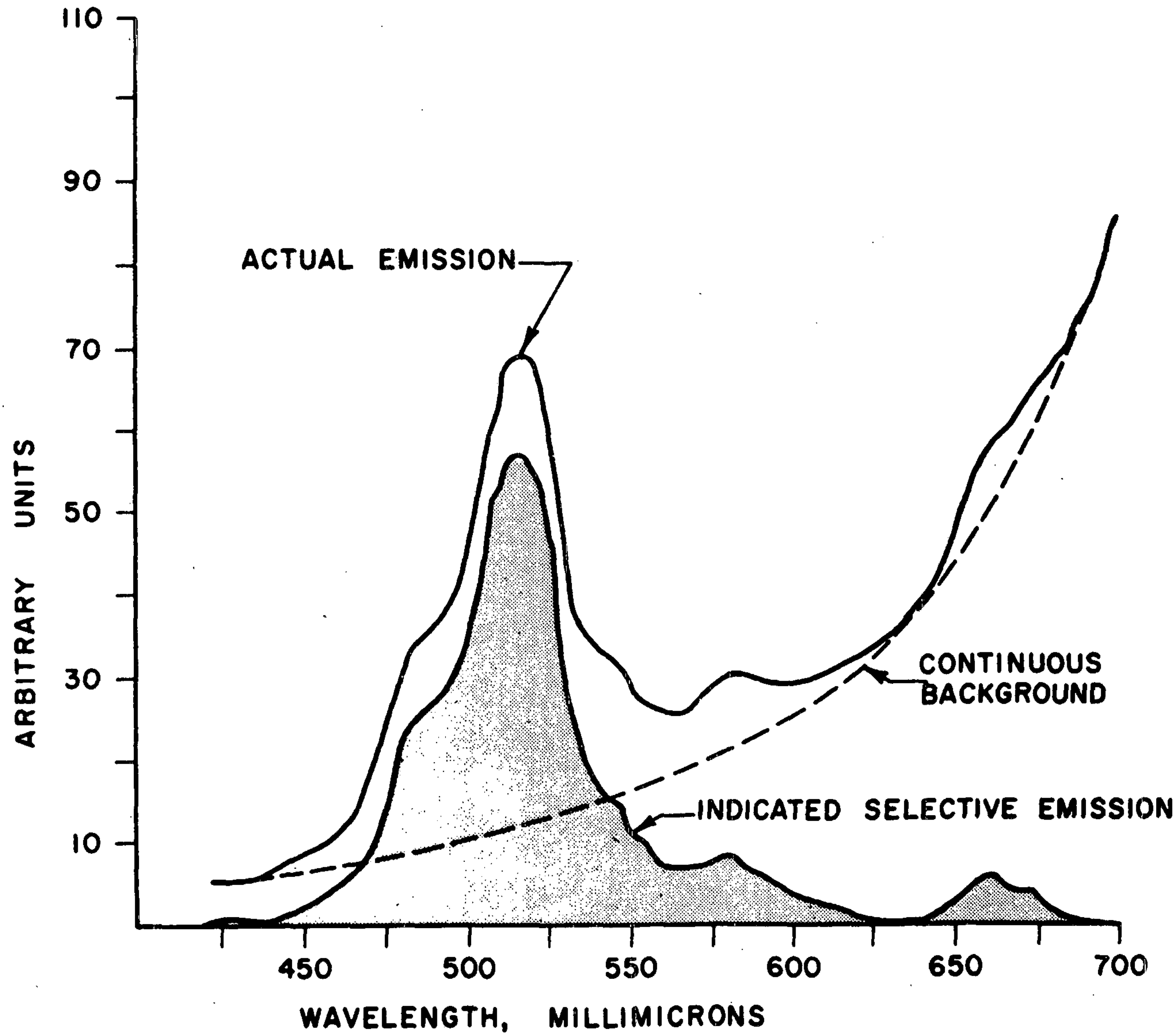

Figure 6-28. Spectral Energy Distribution of Green Flare

of a 105 mm illuminating projectile canister considerably shortened the burning time of the illuminant. The effect of rotational spin on flares loaded in 1.5-inch O.D. steel flare cases was also studied. Examination of burned out flare cases indicated that the resulting centrifugal forces prevents the expulsion of much of the slag. The slag builds up and effectively decreases the internal diameter of the case. This decrease in internal case diameter prevents the efficient expulsion of gases formed and thus causes an increase in the internal pressure. As a result of the pressure increase, the illuminants burn more rapidly. This is substantiated by the fact that flares which are rotated at the slowest speeds (which have the longest burning times) show much less slag residue than those rotated at higher speeds. Flares tested at speeds of 3,000 to 5,000 rpm, however, all contain approximately the same amount of slag.

In another study, the trace duration of a tracer was found to be shortened, as shown in Figure 6-34,[50] by rotational spin. Burning rates for tracer compositions increased with an increase in diameter, or length of tracer column and this increase was more pronounced as angular speed was increased. In general, for each composition the per-

TABLE 6-10
EFFECT OF PARTICLE SIZE ON BURNING RATE AND CANDLEPOWER FOR MAGNESIUM-SODIUM NITRATE-POLYVINYLCHLORIDE-LAMINAC MIXTURE

Ingredients	*Average Particle Size, microns*	*Percentages*			
Magnesium, At., 20/50	437	48			
Magnesium, At., 30/50	322		48		
Magnesium, At., 50/100	168			48	
Magnesium, At., 100/200	110				48
Sodium Nitrate, DR, ULP	34	42	42	42	42
Polyvinylchloride	27	2	2	2	2
Laminac Resin 4116	—	8	8	8	8
		Time-Intensity Data			
Candlepower, 10^3 candles		130	154	293	285
Burning Rate, in./min		2.62	3.01	5.66	5.84

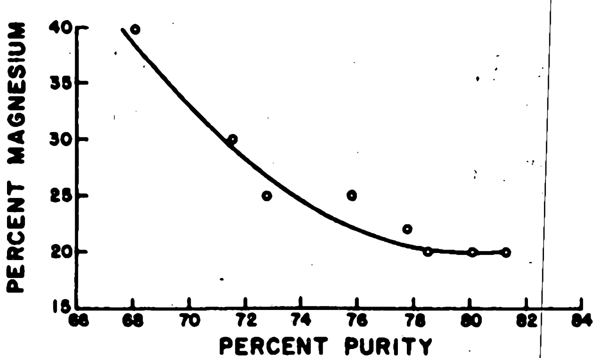

Figure 6-29. Magnesium Content Versus Excitation Purity for a Yellow Flare

centage loss of slag decreased for each diameter with an increase in rotational speed. Total light output expressed in candlepower seconds decreased with an increase in rotational speed.[50]

6-3.5.12 Moisture and Stability

One of the important factors in determining the stability and shelf life of a pyrotechnic item is the sensitivity of the pyrotechnic composition to atmospheric moisture. In the presence of moisture, the oxidant will react with the metal particles to form a layer of metal oxide, metal hydroxide, or both. This nonreactive layer changes the ignition and propagative characteristics of the

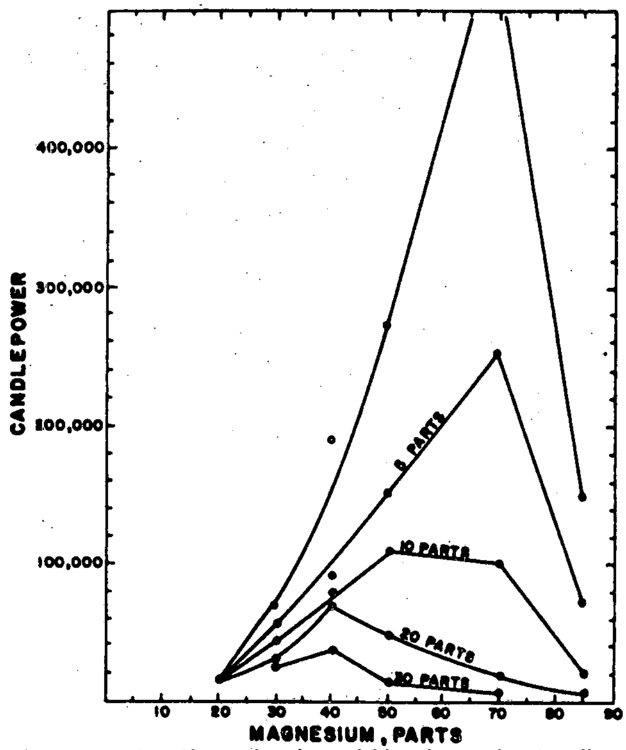

Figure 6-30. Effect of Polyvinylchloride on the Candlepower of Mixtures Containing Strontium Nitrate and Ground Magnesium, Grade A

TABLE 6-11
EFFECTS OF CHANGE IN SPECIFIC SURFACE OF MAGNESIUM PARTICLES

	Ground Magnesium	*Atomized Magnesium*
COMPOSITION, %		
Ground magnesium	66.6	—
Atomized magnesium	—	66.6
Sodium nitrate	28.6	28.6
Resin	4.8	4.8
	(100.0)	(100.0)
CHARACTERISTICS		
Candles per sq in.	200,000	178,000
Burning rate, in./min	9.4	.57
Density	1.56	1.65
Candle-seconds/gram	50,000	69,200

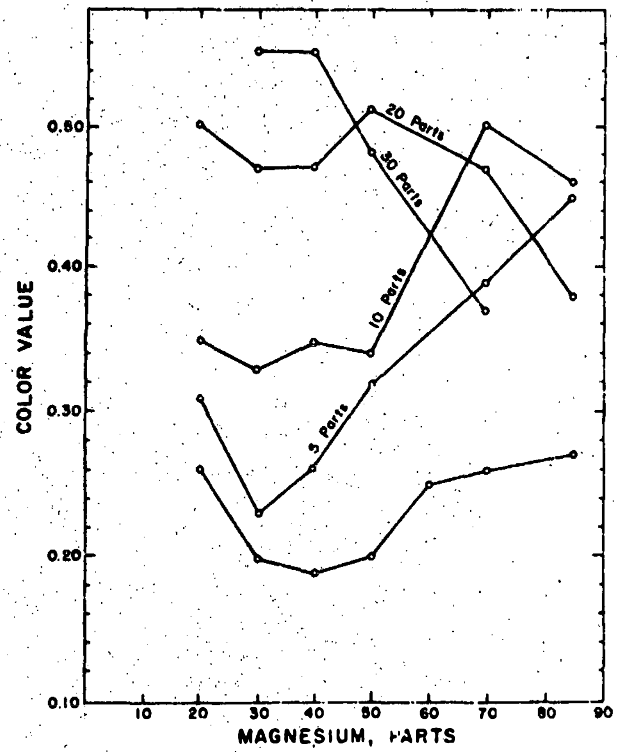

Figure 6-31. Effect of Polyvinylchloride on the Color Value of Mixtures Containing Strontium Nitrate and Ground Magnesium, Grade A

pyrotechnic mixture so that reduced luminous intensity or nonignition may result.

The critical relative humidity is a measure of the sensitivity of oxidants to moisture. It is determined by exposing samples of the oxidizers to atmospheres of known relative humidities and determining the change in weight of the oxidizer. The critical relative humidity is that at which, with respect to moisture content, the oxidizer is in equilibrium with its surroundings. Roughly, the higher the critical relative humidity, the less soluble the oxidant. Small traces of impurities may lower the critical relative humidity of a compound.

In some cases, it has been found expedient to compromise due to an oxidizer's excellent oxidizing ability. This has been the case with sodium nitrate that formerly had a critical humidity of 50 percent for the specification grade. The use of U.S.P. double-refined sodium nitrate with a critical

TABLE 6-12
EFFECTS OF LOADING PRESSURE ON BURNING CHARACTERISTICS OF MAGNESIUM-SODIUM NITRATE FLARES

Loading Pressure, Psi	*Luminous Intensity, 1000 Candles*	*Total Light, 1×10^6 Candle-Seconds*	*Burning Rate, Inches Per Minute*	*Burning Rate, G Per Second*	*Color Ratio*	*Chromaticity Cordinates, x*	*y*	*Luminous Efficiency, 1000 C-Sec Per Gram*	*Composition Density, Grams Per CC*
2,000	278	7.2	6.20	6.51	0.036	0.48	0.46	42.6	1.54
4,000	292	7.0	6.33	7.20	0.036	0.48	0.46	40.7	1.64
7,000	262	7.1	5.62	6.75	0.037	0.48	0.46	38.7	1.74
10,000	270	7.8	5.47	7.12	0.085	0.48	0.46	37.9	1.90
15,000	286	7.4	5.63	7.69	0.035	0.48	0.45	37.2	2.03
20,000	291	7.6	5.67	7.55	0.035	0.48	0.46	38.6	1.95
25,000	290	7.5	5.92	7.69	0.037	0.48	0.45	37.8	1.88

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TABLE 6-13
EFFECT OF SIMULATED ALTITUDE AND TEMPERATURE ON ILLUMINATION CHARACTERISTICS OF YELLOW SIGNALS

		LOT Y-1			LOT Y-2		
Simulated Altitude, Feet*	*Temperature, °F*	*Average Luminous Intensity, Candles*	*Burning Time, Seconds*	*Yellow** Color Value*	*Average Luminous Intensity, Candles*	*Burning Time, Seconds*	*Yellow** Color Value*
0	70	53,300	19	.038	124,000	9.3	.052
10,000	70	39,200	21	.047	113,000	11	.062
20,000	70	19,200	24	.058	91,000	9.5	.062
40,000	70	6,650	49	.064	55,000	12	.072
0	—65	44,500	16.5	.055	78,000	9.5	.074

* Pressure reduced to simulate condition at altitudes shown.
** The color value was determined using the procedure given in PA Tech Report No. 1385.

TABLE 6-14
EFFECT OF SIMULATED ALTITUDE AND TEMPERATURE ON ILLUMINATION CHARACTERISTICS OF RED SIGNALS

		LOT R-1			LOT R-2		
Simulated Altitude, Feet*	*Temperature, °F*	*Average Luminous Intensity, Candles*	*Burning Time, Seconds*	*Red** Color Value*	*Average Luminous Intensity, Candles*	*Burning Time, Seconds*	*Red** Color Value*
0	70	26,400	18.3	.44	48,000	14	.56
10,000	70	17,200	22.5	.47	30,000	19	.59
20,000	70	14,500	27	.53	25,700	22	.60
40,000	70	9,300	41	.62	15,500	35	.69
0	—65	25,400	16.5	.40	38,000	14.5	.60

* Pressure reduced to simulate condition at altitudes shown.
** The color value was determined using the procedure given in PA Tech Report No. 1385.

humidity of 75 percent partly alleviated this problem.[43]

The effect of moisture on a finely powdered metal can be determined by placing a sample in distilled water and maintaining the system at a specified constant temperature. By collecting the gas evolved at constant pressure, the rate of corrosion of the metal can be established. For atomized magnesium,[51] it was found that the rate of corrosion increased with time but only slightly between the temperatures of 30°C and 65°C. Atmospheres of nitrogen and oxygen exerted only a slight influence on the corrosion rate whereas hydrogen and carbon dioxide were observed to have retarding and accelerating effects, respectively. Further, the rate of corrosion increased with an increase in specific surface.

One way that the deleterious effect of moisture on magnesium or other metal can be avoided is to coat the metal with a thin chromate film. Protection of the atomized magnesium in consolidated illuminating and signal compositions may also be

TABLE 6-15
EFFECT OF SIMULATED ALTITUDE AND TEMPERATURE ON ILLUMINATION CHARACTERISTICS OF GREEN SIGNALS

		LOT G-1			LOT G-2		
Simulated Altitude, Feet*	*Temperature, °F*	*Average Luminous Intensity, Candles*	*Burning Time, Seconds*	*Green** Color Value*	*Average Luminous Intensity, Candles*	*Burning Time, Seconds*	*Green** Color Value*
0	70	14,300	16.5	.36	38,700	16	.35
10,000	70	14,300	21.5	.39	20,500	15	.36
20,000	70	11,500	26.5	.37	20,500	17	.36
40,000	70	11,000	30	.41	19,500	26	.35
0	—65	27,800	20	.36	35,700	15	.35

* Pressure reduced to simulate condition at altitudes shown.
** The color value was determined using the procedure given in PA Tech Report No. 1385.

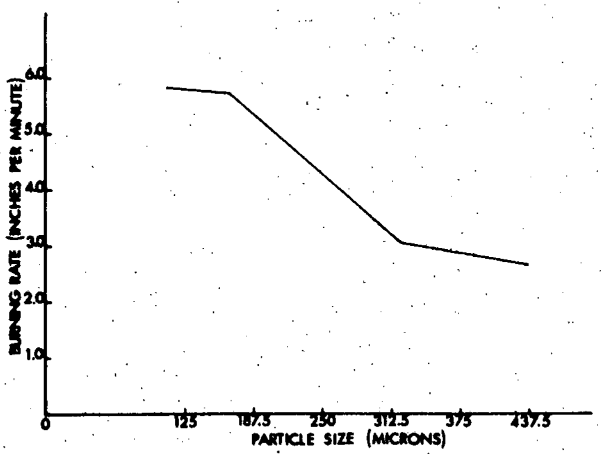


Figure 6-32.1. Burning Rate vs Particle Size of Magnesium

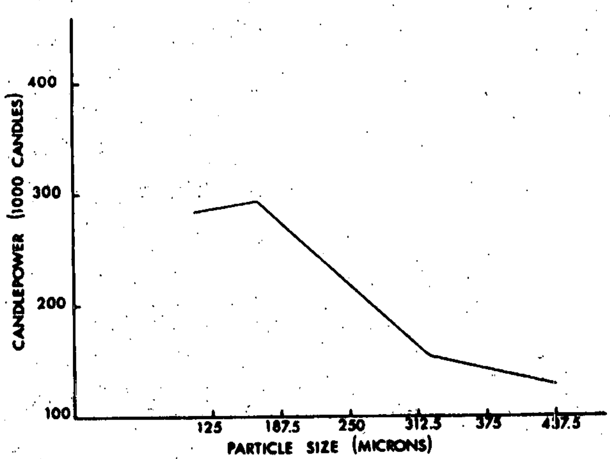


Figure 6-32.2. Candlepower vs Particle Size of Magnesium

accomplished by the use of binders and waterproofing agents, usually an oil, wax, or plastic resin. Containers and nonhygroscopic first-fire compositions are used to keep moisture from the main illuminating compositions.

6-4 NONCONSOLIDATED ILLUMINANT CHARGES

As pyrotechnic reactions, in general, are based on the chemical reaction of a fuel with an oxidizer, the manner in which these two basic ingredients are incorporated into a pyrotechnic device will greatly influence its performance. Nonconsolidated illuminants differ from consolidated illuminants because they do not contain binders and are loose-loaded which changes the manner in which they react to produce light. Consolidated compositions burn comparatively slowly while nonconsolidated mixtures, under confinement, react rapidly producing a bright flash of light.

The major uses for nonconsolidated illuminant charges are in photoflash bombs and cartridges for night aerial photography, and in spotting charges for tracking and acquisition purposes. Nonconsolidated fillers include: (1) intimate mixture of a powdered metal and powder oxidant, (2) a powdered metal, such as aluminum, magnesium, or their alloys, and (3) a powdered metal and a

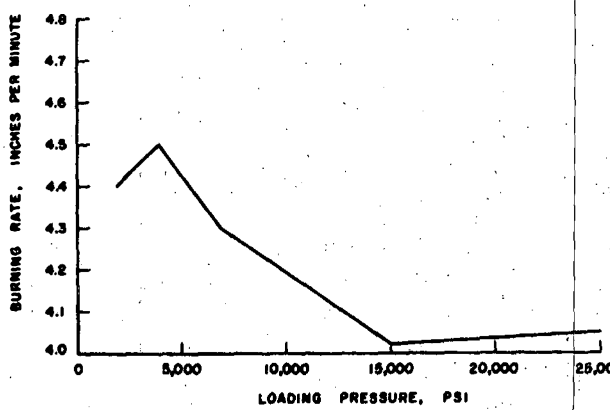


Figure 6-33. Effect of Loading Pressure on Burning Rate of Pyrotechnic Compositions

powdered oxidant segregated from each other in concentric cylinders.

6-4.1 AERIAL PHOTOGRAPHIC ILLUMINANTS

The mission of aerial photography is to obtain information regarding the static content of an area (buildings, roads, etc.), and the movement of personnel and equipment. At night, this requires a light source that will produce sufficient illumination to obtain usable negatives. High intensity light sources for night aerial photography may be broadly divided into two classes, pyrotechnic light sources, and the electronic flash tube.[52] As flash tubes are unable to produce as much light as pyrotechnic light sources, their use is limited to low altitudes. At higher altitudes, photoflash cartridges and photoflash bombs are the only practical sources of intense illumination for night aerial photography using conventional aerial cameras and photographic film.

The film speed, basically, determines the amount of light which must fall on the film in order to obtain a satisfactory negative. The amount of light which reaches the photographic film depends on:

a. Amount of light reflected from the area to be photographed, which depends on the illumination and the terrain reflectance of the area,

b. Relative aperture of the camera lens which is normally expressed by f values on a lens barrel are the diameter of the lens aperture divided by the focal length of the lenses. The transmission characteristics of the atmosphere determine the portion of the light reflected from the area to be photographed which reaches the photographic film, and

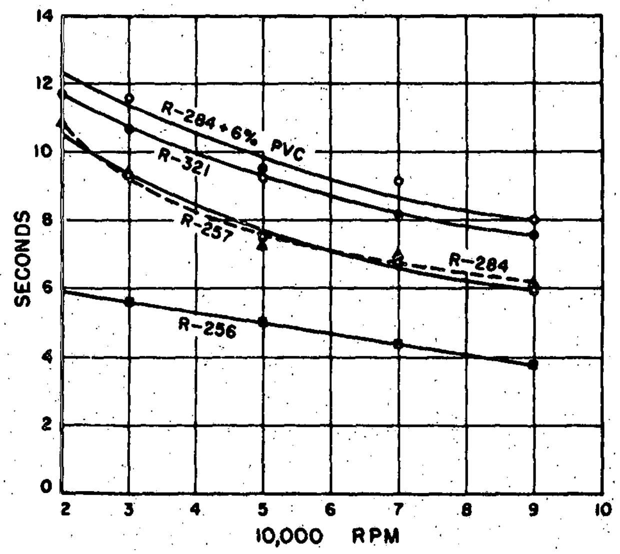


Figure 6-34. Effect of Spin Upon Trace Duration of Various Standard Tracer Compositions When Loaded Into Caliber .50 M1 Jacket

c. Exposure time which, for night aerial photography, may be the duration of illumination and not the shutter speed.

The intensity of the light source and its relative location determine the illumination received by the area to be photographed as well as the uniformity of the illumination produced. As shown in Figure 6-35, the location of a pyrotechnic light source can be specified by giving the trail angle and the burst altitude. The trail angle must be sufficiently greater than the camera half-angle to assure that only the reflected light from the area being photographed will reach the camera lens.

For a normal trail angle value, the optimum burst altitude has been determined to be about 0.6 of the flight altitude, when the required intensity of the light source is a minimum.[53] At the optimum burst height the amount of light required for a satisfactory negative is approximately:[52]

$$I = \frac{6.4U_t(\lambda f)^2}{T} \qquad (6\text{-}16)$$

where I is the candlepower of the light source, T is the exposure time, f is the effective f value for the lens, λ is the slant distance from the camera

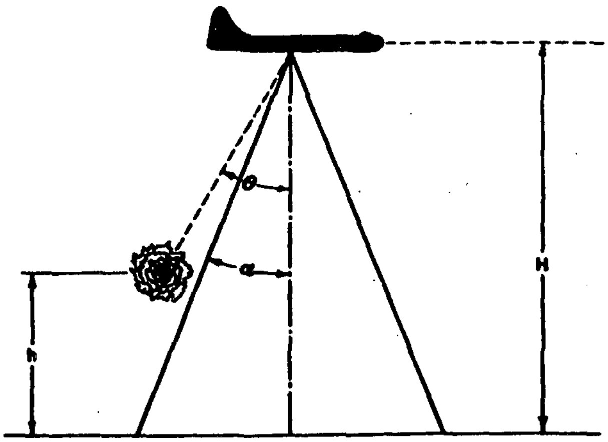


Figure 6-35. Diagram of Bomb Burst and Trail Angle

lens to area being photographed, and U_t is a factor best determined experimentally. However, as shown in Figure 6-36 (which is a typical characteristic curve for black and white negative material), it is impossible to estimate the exposure U_t required to produce a negative of satisfactory photographic density. Military specification for film is based on the reciprocal of twice the exposure of a point on the curve at which the slope of the longest is one-half gamma; for this film the military speed is 300 ASA. A satisfactory exposure would correspond to about one-half way up the linear part of the characteristic curve, i.e., for this material an exposure of approximately 0.05 log E units.

6-4.1.1 Photoflash Cartridges

Illumination for relatively low altitude night aerial photography is furnished by photoflash cartridges. As shown in Figure 6-37, these cartridges contain a photoflash charge and a delay fuze assembled into a charge case. This subassembly is put into an electrically primed outer cartridge case along with a small expelling charge. The cartridges are loaded into specially designed ejectors. Ejection and functioning of the cartridge are initiated by an electric pulse which causes the electric primer to function which, in turn, ignites the expelling charge which ejects the inner charge. At the same time, the delay fuze is initiated and, at the end of the delay time, a relay explosive charge is initiated and, in turn, initiates the photoflash mixture. As the delay time determines the location of the burst behind (and below) the aircraft, the proper delay time will depend on the speed of the aircraft during the photographic mission. For this reason, photoflash cartridges are furnished with the different delays indicated in Table 6-16 which summarizes the characteristics of some photoflash cartridges. Characteristics of a typical photoflash composition are shown in Table 6-17.

6-4.1.2 Photoflash Bombs

Illumination for high altitude night photography is provided by photoflash bombs which are released from the aircraft during the photographic run. A typical photoflash bomb is shown in Figure 6-38. Descriptive data and characteristics of photoflash bombs containing photoflash powder are summarized in Table 6-18.

Photoflash bombs containing a relatively large amount of flash powder can be very dangerous since they can be exploded by impact. Because of this danger, dust-type photoflash bombs were developed. The characteristics of dust-type photoflash bombs are summarized in Table 6-19.

In 1950, the development of a segregated oxidant bomb in which the burster oxidant and metal dust were loaded separately in coaxial cylinders was started. Such a configuration appeared to offer the possibility of safety from impact initiation, and also of producing the high peak candlepower of the flashpowder bomb, along with the broad peak associated with the metal dust-type photoflash bomb. No photoflash bombs of this type were standardized. Results obtained with some experimental segregated oxidant bombs are summarized in Table 6-20.

6-4.1.3 Other Photographic Illuminant Systems

Attempts have been made to increase the output of the standard flash bulb by a factor of 100 so that it could be used as a night aerial photographic illuminant. Unfortunately, it was found that this increase could not be obtained without incurring

TABLE 6-16
DESIGNATION AND DESCRIPTION OF PHOTOFLASH CATRIDGES

Cartridge Designation	Size, in. L × Dia	Total Weight, lb	Powder oz	Powder Formula Type	Powder Formula Class	Peak Intensity, 10^6 Candles	Time to Peak, msec	Integral Light, 10^6 Candlesecs, CPS Total	Integral Light, 10^6 Candlesecs, Best CPS_{40}	Duration of Flash, msec	Casing	Fuse
T10	7.71×1.56	—	5.25	II	B	24	5	0.77	—	—	Standard M11 Signal case	Time delay 1 to 5 sec
T12	7.73×1.57	0.73	5.75	II	B	50	5	1	—	30	Modified M11	Time delay 1,2, or 4 sec
M112	7.73×1.57	1	7	III	A	110	3	1.4	—	30	Modified M11	Time delay 1,2, or 4 sec
M123 (T89)	8.37×2.9	7	27.2	III	A	240	4	5	4.8	40	Al	Obturated delay fuse, 2,4, or 6 sec
T90	About same as M112	About same as M112	—	Each star: (b) $NaNO_3$/atomised Mg binder, 80/70/2		8.6	--	2.5	—	690	Outer case similar to M112; contains 5 stars	Obturated delay fuse, 1 or 2 sec
T102	8×1.75	1.25	12	III	A	169	4	2.4	--	31(a)	Al, 0.051 in. wall	Obturated delay fuse similar to M123
T103	11×2.375	5.5	27.2	III	A	325	4	7.2	6.6	47(a)	Al, 0.051 in. wall	Similar to M123

(a) to 0.1 max.
(b) Contains a high intensity illuminating composition, not photoflash powder.

disadvantages which essentially nullified any gain in output.

Other pyrotechnic light sources have been tried which were designed to produce illumination on a continuous basis rather than in short bursts for use with strip-type cameras which do not contain a shutter. The film is moved continuously across a slit at a speed which matches that of the image motion. One of the early attempts was the use of the T90 photoflare cartridge. This consisted of the same casing as the M112 with a charge of five stars which were made of a high intensity consolidated illuminating composition. The light output was not adequate as no visible image was obtained on the negatives exposed in flight test at 1000 feet.[54] Another attempt was a burner for magnesium dust which was developed for use on aircraft.[55,56]

6-4.2 SPOTTING CHARGES

Spotting charges are used for locating point of impact, for target acquisition, for tracking, and for indication of item or component functioning. For many years, spotting charges of black powder were used in practice bombs and projectiles to locate point of impact. Because the observation distances were relatively short and because a relatively large volume was available for the spotting charge, an adequate flash could be produced with black powder. The development of long range missiles, as well as the use of small arm projectiles as spotting rounds for major caliber weapons, led to a requirement for more effective spotting charges.

6-4.2.1 Small Arm Spotting Rounds

Small caliber spotting rounds can be used to aim a major caliber weapon. In operation, the small caliber spotting rifle, which is rigidly attached to the main weapon, is fixed and the point of impact is indicated by a flash of light and a puff of smoke formed by the functioning of the small caliber spotting projectile. As the trajectory of the small arm spotting projectile and that of the main round are nearly identical at the critical range, the burst provides information for adjustment of aim. A hit with the spotting round means that the main projectile will also strike close to the target.[57,58]

A typical 20 mm spotting round is shown in Figure 6-39. This round contains about 6.5 cubic centimeters of a flash mixture and can produce a flash of 1.5 million candlepowder with a duration of 700 milliseconds.

6-4.2.2 Tracking

Highly accurate trajectory information is required in the development of a missile system. One method of obtaining this information for a missile at high altitudes is to photograph the flash

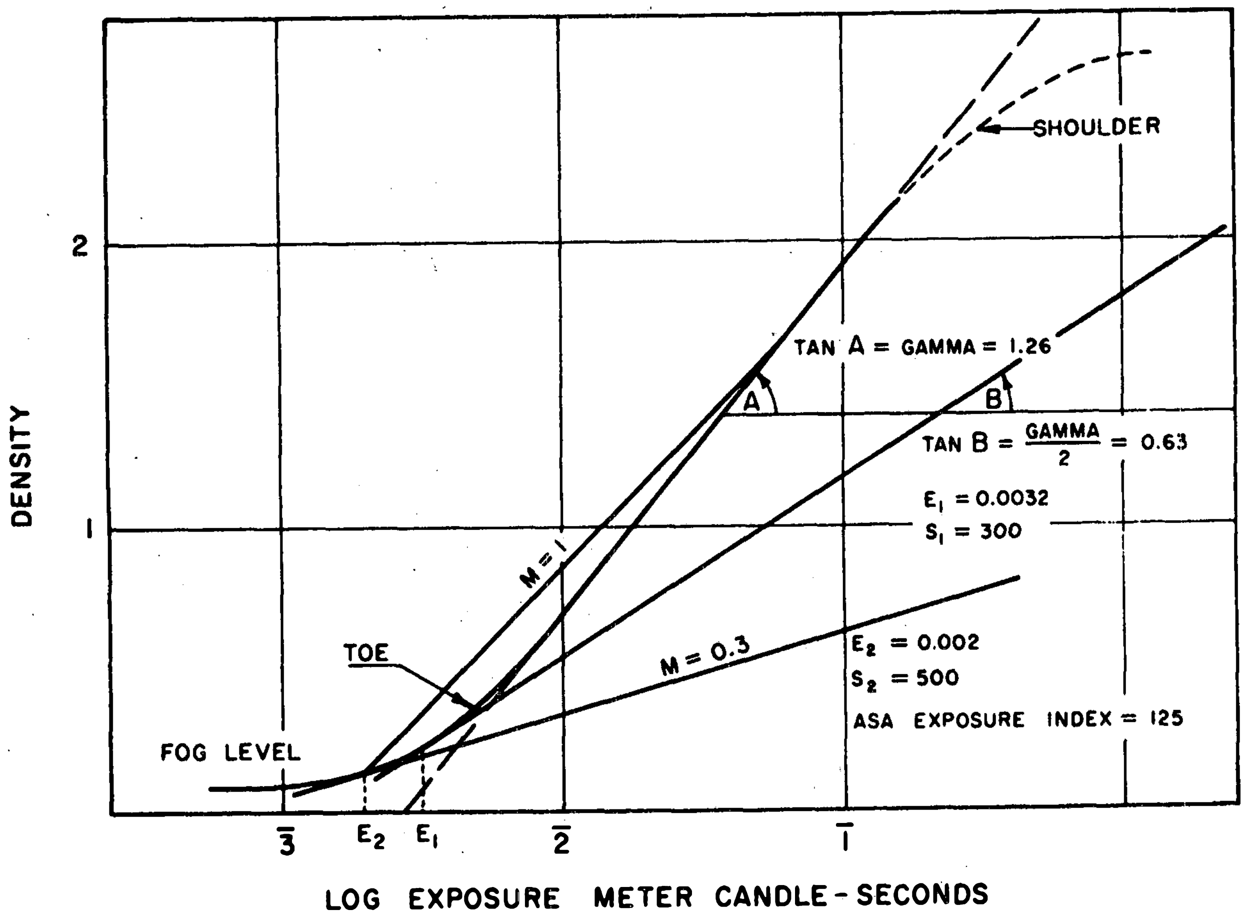


Figure 6-36. Typical Characteristics of Black and White Negative Material

produced by a photoflash cartridge ejected a distance sufficient to prevent damage to the missile in flight. Flash cartridges of the type shown in Figure 6-40 (which are of the same general type discussed in Paragraph 6-4.1.1) were developed for this purpose. Modifications to reduce weight and simplify mounting problems resulted in a flash device which produces a series of flashes with a known time interval between them.[59]

6-4.2.3 Indication of Functioning

Flash charges are used also to provide a visible indication of the functioning of an item or component such as a warhead fuze. The flash signal provides a brilliant light flash and can be photographically recorded by remote cameras, providing data so that the time and location of functioning can be accurately determined.[60,61] A typical flash charge for this purpose is shown in Figure 6-41.

6-4.3 TYPICAL COMPOSITIONS

Typical nonconsolidated illuminating compositions used as photoflash and spotting charges are summarized in Table 6-21.

6-4.4 Light Production

As has been indicated, nonconsolidated illuminants differ from consolidated illuminants in the manner in which they react to produce light. Consolidated compositions propagatively burn in a relatively slow manner while nonconsolidated compositions react rapidly producing a bright flash of light. Because of the rapidity of the reaction, functioning of devices containing noncon-

TABLE 6-17
CHARACTERISTICS OF TYPE III PHOTOFLASH COMPOSITION

Ingredients:	*Specification*	*Microns*	*Percent*
Aluminum, atomized	JAN-A-289	15	40
Potassium Perchlorate	PA-PD-254	24	30
Barium Nitrate	PA-PD-253	147	30

Physico-Chemical Data:

Heat of Reaction, cal/g—2774 (calc)
Reaction Temperature, °C—approx. 3500
Gas Volume, cc/g—24 (calc)
Tapped—1.67
Vac. Stab, 120°C, cc gas/40 hrs—0.16

Sensitivity Data:

Impact:	PA, inches—40+
Friction Pend:	Steel—Crackles; Fiber—No Action
Ignition Temp, °C:	5 sec value—610; DTA—No Ignition
Hygroscopicity:	57% RH, room temp; Hrs 24; % Wt Gain < 0.1
Electrostatic Sensitivity:	Joule, Min 2.14; 50% Pt—3.5; 100% Pt—4.5
	Temp—65°F; % RH—40; Unconfined—Yes

solidated illuminants can cause disruptive effects in their surroundings similar to the effects produced by high explosives.

6-4.4.1 Light Output Characteristics

The light produced by the functioning of a device containing a nonconsolidated illuminant is characterized by its relative high peak intensity and the relatively short flash duration.

6-4.4.1.1 Time Intensity[62,63]

A typical time-intensity curve for the light produced by the functioning of a photoflash device containing a flash powder (intimate mixture of powdered metal and oxidant) charge is shown in Figure 6-42. The curve for most spotting charges would be similar. As indicated in this figure, the important characteristics of the light output of a photoflash device are: (1) total amount of light produced (candleseconds), (2) amount of light produced in the best 40 milliseconds, CPS_{40} (candleseconds), (3) peak intensity (candles), (4) time to peak intensity (milliseconds), and (5) duration of the flash (milliseconds). The total amount of light produced determines the maximum exposure which can be obtained at any altitude, using open shutter techniques where the duration of the flash determines the exposure time. Unless image movement compensation techniques are used, the speed of the aircraft must be low enough that image relative movement will not result in unacceptable photographic definition. Until the development of image motion compensation techniques, many night aerial photographs were made with an exposure time of $\frac{1}{25}$ second (40 milliseconds). In this case, the exposure obtained depended on the amount of light produced in 40 milliseconds, and the maximum photographic exposure was obtained with the shutter open for the best 40 milliseconds. (See Figure 6-43.) Peak candlepower is important as it greatly influences the amount of light produced in the best 40 milliseconds. The time-to-peak, and the variation in the time-to-peak are important for synchronization of the shutter open time and the best 40 milliseconds of the light flash.

Dust-type photoflash devices produce flashes

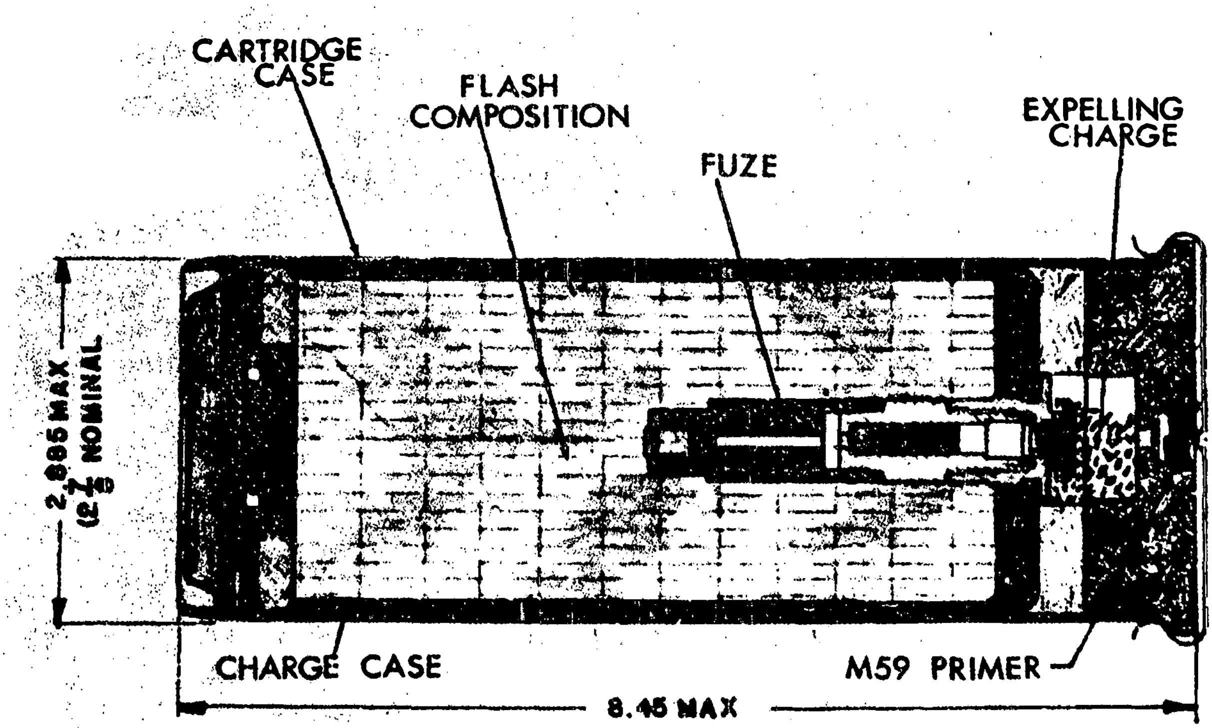


Figure 6-37. Typical Photoflash Cartridge

which have lower peak intensities and longer durations than those produced by devices containing flash powders, as shown in Figure 6-44. Image compensation techniques are normally required when dust-type photoflash bombs are used in order to efficiently utilize the light produced.

6-4.4.1.2 Spectral Distribution

As shown in Figure 6-45, the spectral distribution curve of the light produced by a photoflash device consists of an intense continuous background on which a discrete spectra is superimposed.[64] The spectral distribution of the radiation produced by a dust-type photoflash bomb is similar.

While the more efficient photoflash compositions at low altitudes produce light which is mainly continuous, the more efficient compositions at high altitudes (100,000 feet) are those which produce an extensive discrete spectra in the visible.[65,66] (See also Paragraph 6-4.5.)

6-4.4.2 Nature of the Photoflash Burst[67,68]

The light-producing characteristics of a flash item depend principally (as discussed in greater detail in Paragraph 6-4.5) on the composition, the amount and shape of the explosive which is used to initiate the composition, and the case. Flash radiographic studies show that when a relatively small amount of high explosive—centrally located in a case containing photoflash powder or metal dust—functions, a bubble of explosion products is formed in the first few microseconds of the initiation of the explosive. The shape of this bubble and the rate at which it expands are dependent on the properties of the material surrounding it, as well as that of the explosive initiator. For example, the shape of the bubble produced by a small quantity of explosive in flake aluminum which has a low density tends to be influenced more by the nature of the explosive and its confinement than the bubble produced in an-

1339/1710

TABLE 6-18
DESIGNATIONS AND DESCRIPTIONS OF FLASH POWDER PHOTOFLASH BOMBS

Bomb Designation	Size, in. L × Dia.	Total Wt, lb	Powder Wt, lb	Powder Formula Type	Powder Formula Class	Peak Intensity, 10^6 Candles	Time to Peak, msec	Integral Light 10^6 Candleseconds CPS Total	Integral Light 10^6 Candleseconds Best CPS_{50}	Duration of Flash, msec to 0.1 max.	Casing
M12 (T1)	32×7.25	32	25	I	—	325	10	—	—	250(a)	Paper tube divided into 2 compartments; powder filled 4/5 of volume; plywood partition; 2 grenade fuses and parachute in 1/5
M23 (T2)	25×4.25	10	7	I	—	100 to 300	—	13.5	—	—	Fiber cylinder; later fitted with steel outer case for improved ballistics
M46 (T3)	48×8	50	25	II	A,B	770	18	50	26	140	Inner fiber charge container; outer steel case 0.03 in. wall
T4	Enlarged M46	—	50	II	B	970	20	65	36.4(c)	—	Light weight sheet metal case, powder in fiber container
T5	Enlarged M46	—	100	II	A	1670	20	132	71.5(c)	—	Light weight sheet metal case, powder in fiber container
T6 (M60)	31.72×4.92	25	10	II	B	300	11	15.4	8(c)	—	0.0239-in. wall. Thin metal case
T6E1						—	—	—	—	—	0.026-in. wall
T6E2						500	—	—	—	—	0.048-in. wall
NDRC Types 1-6	58×10.75	200	80 to 88	Various		Best 1700(b)	15(b)	118(b)	Best 60.5(b,c)	—	250-lb TI casing
T9		145	70	II	B	850	2	99	30	270	
T9E1	30×8	115	35	II	B	—	—	—	—	—	125-lb demolition bomb, case, 0.19 in.
T9E4-6		—	—	Various		—	—	—	—	—	wall
T9E8	35×8	166	70	III	A	2100	5	140	65	153	M70; 0.19-in. wall
M120	52.25×8	150	70	III	A	3490	6	165	75.6	153	Modified M70 chemical bomb body, box type fin, 0.188-in. wall
M120 III B	52.25×8	165	85	III	A	4490	6	223	95.9	188	Same as M120
T92	39×11	280	138	III	B	5840	5	290	140.5	226	Optimum design to fit in RB-4 aircraft; shallow, wide fin
T93	59.16×14.18	496	224	III	A	4000	5	373	108	255	500-lb G.P. bomb casing, AN-M46; M109 fin assembly
T94	69.5×18.8	926	450	III	A	5600	65	666	163	299	1000-lb G.P. bomb casing AN-M65
T99	4.25 or 13	95 to 160	70	—	—	—	—	—	42	—	Thin copper casing, or steel, 0.0625 to 0.5-in. wall
T104			64 or 104 (thin case)	III	B	(End on) 2900 3570 (thin case)	4 6	189 284	82 88	163 228(a)	Modified M30A1 100-lb G.P. bomb body; or thin case model, modified M47A3 chemical bomb body

(a) Total duration (b) With Type II, Class B powder (c) During 0-50 msec

odized aluminum. The subsequent shape of the bubble in the metal dust depends on the resistance encountered in different directions. If the confining case deforms slowly without rupture, the shape of the explosion products will tend toward the shape of the deformed case. If the case ruptures quickly at one point, the dust may be forced through this opening while some of the dust will remain in the case. For small quantities of explosive, the shape of the explosive is of little importance. For larger quantities of explosive, the shape and its method of initiation must be considered. An extreme example is an end-initiated line charge axially located in a surrounding cylinder of metal dust. In all cases initiation and burning of the dust takes place in the air after case breakup.

If the surrounding material can react rapidly, gases resulting from the vaporization of the reactive material at the outer surface of the expanding bubble of explosive products will increase the rate at which the bubble expands. The amount of this contribution depends on the reactivity of the mixture. The piston action of the expanding bubble forms a spherical shell of compressed flash composition. Rapid chemical reaction starts at the shock front when it reaches the case and the increase in pressure results in case rupture. After

TABLE 6-19
CHARACTERISTICS OF DUST PHOTOFLASH BOMBS

Bomb Designation	Size, in. L×Dia	Total Wt, lb	Powder		Peak Intensity, 10^6 Candles	Time to Peak, msec	Integral Light 10^6 Candlesecs		Altitude Flown, ft	Burst Altitude and Position, ft	Duration of Flash, msec to 0.1 max	Casing	Burster
			Wt, lb	Formula			CPS Total	Best CPS_{40}					
T7	46.72×8	65(?)	39	Mg, Grade B	—	—	—	—			—	Modified M46 case with dust charge	
T8	40×10.76	200	70	Flake Mg, Grade B	41	44	9	1.9[a]			—	Modified 250-lb AN-M57 G. P. Bomb case, 0.2-in. wall	Tetryl; conical; tinplate container
T8E1		150	35	Flake Al, Grade A	1100	10	49.4	35.1			—		
T9E2	36×8	103	17	Flake Al	42	—	39	—			—	125-lb demolition bomb case, 0.19-in. wall	Tritonal 5 lb
T9E3	36×8	125	40	Pigment Al/S, 75/25	38	—	45	—			—	Same as T9E2	
T9E7	35×8											Sheet steel, 0.06 in. wall; casing/burster diam. ratio: 4:1	2 in. diameter each:
Type 1			52	Atomized Mg	650	14	20	—			—		Tritonal, 5.8-lb
2			52	Atomized Mg	600	13	20	—			—		Sodatol 6.1-lb
3			60	Atomized Mg-Al alloy	1300	13	30	—			—		Tritonal 5.8-lb
4			60	Atomized Mg-Al alloy	1200	15	25	—			—		Sodatol 6.1-lb
5			21	Flake Al	750	13	25	—			—		Tritonal 5.8-lb
6			21	Flake Al	550	14	20	—			—		Sodatol 6.1-lb
T83 (Ballistic Design)	66×8	100(?)	55	—							—	0.2-in. case thickness	—
T86E1-4	35×8 35×10 29×11 24×12	85	70	Various metal dusts	Varied: 1400–2450	Varied: 34–121	Varied: 164.5–660	Varied: 50–94	25,000–35,000	5,000–15,000	119–812	M47 chemical bomb case; 0.06 in. wall	Various
M122 (T86E2)	54×8	110	75	Atomized 65/35 Mg-Al alloy (20± 5 microns)	820	50	—	31.9	5,000–20,000	8,000; 30° trail angle best	—	—	M26, 1-in. diam. cylindrical; 2-lb cast 70/30 tritonal; M147E1 fuse
T86E5	13 diam.	—	—	Atomized Al	—	—	—	—			—	Thin Al or steel	TNT and booster
0-69	27.5×4	18	9.5	Al dust and $KClO_4$ segregated	672	28	—	20.2			82	Concentric burster, oxidant, metal dust tubes	Hand packed TNT; Tetryl booster; M146 fuse
0-70	48.6×8	96	70	Same as 0-69	Best, 3490	42		Best, 130	To 30,000	At least 13,000; 30° trail		M46 case adapted to concentric loading	Hand packed TNT; Tetryl booster; M146 fuse
T115	54×8	110	84	Same as 0-69	Best, 1470	28		Best, 48.9	To 30,000	At least 13,000 30° trail angle best	—	Modified M47A3 chem. bomb case	Larger than 0-70 burster
X52	39×10	175	114.2	Same as 0-69	Best, 4890	—	—	160			—	Concentric casing, specially designed	Hand tamped crystalline 2-in. TNT, 4-lb; Tail fuse
X53	23×8	50	34.3	Al with 3% SiO_2 gel, $KClO_4$	—	—	—	—			—	Concentric casing, specially designed	1.7-lb hand tamped TNT, Tetryl booster; Tail fuse

[a] During 0–50 msec

TABLE 6-20
SEGREGATED OXIDANT PHOTOFLASH BOMBS

Bomb Designation	Size in. L×Dia.	Total Weight, lb	Powder		Central Burster	Peak Intensity, 10^6 Candles	Integral Light 10^6Candlesecs, Best 40ms. Period
			Outer Shell	Inner Shell			
0-69	4×27.5	18	8.4 lb Al dust	3.1 lb $KClO_4$	TNT burster	672	20.2
0-70	M46 casing	96	Al dust 70 lb total chg.	$KClO_4$	TNT	3490	130
T115	M47A3 Chemical bomb case	110	Al dust 84 lb total chg.	$KClO_4$	TNT	1470	48.9
X52	10×30	175	Atomized Al 78 lb	36 lb $KClO_4$	TNT	4890	130
X53	8×22	50	Atomized Al 25 lb-3% silica gel	12 lb $KClO_4$	TNT	2200 (expected)	74 (expected)

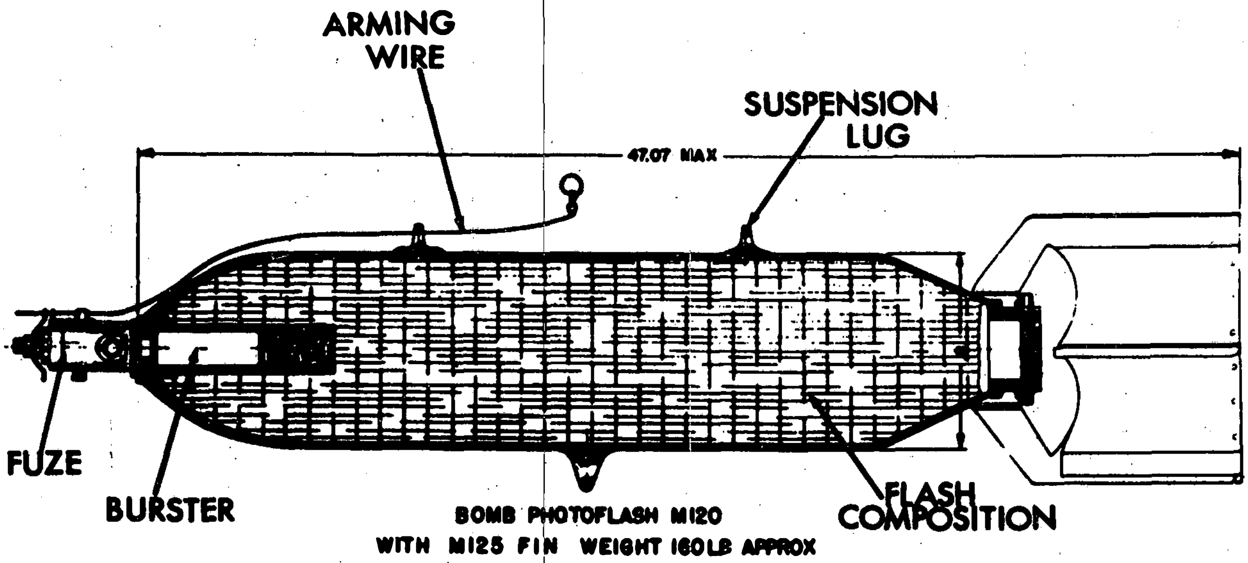


Figure 6-38. Typical Photoflash Bomb

case rupture the cloud expands against the atmospheric pressure, resulting in cooling of the cloud. The cloud must contain fairly large sized particle aggregates (approximately 250 microns)[18] so as to reach the size observed experimentally. The light output reaches a peak value and then slowly decreases.

6-4.5 FACTORS AFFECTING PERFORMANCE

The light output of bright flash-producing devices is dependent upon many interrelated factors. Some of the more important of these factors are: (1) charge weight, (2) composition, (3) particle size, (4) burst diameter and shape, (5) igniters and bursters, (6) confinement, and (7) ambient pressure.

6-4.5.1 Charge Weight

Generally, flash powder in items which produce a burst approaching a spherical shape (see also Paragraph 6-4.5.4) develop a total light output which is proportional to the charge weight (as is

TABLE 6-21
TYPICAL COMPOSITIONS FOR PHOTOFLASH AND SPOTTING CHARGES

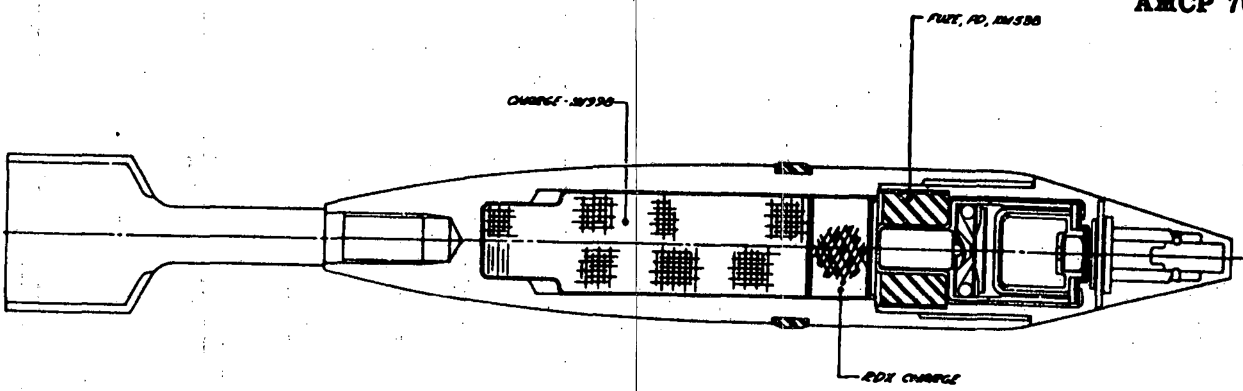
Type	Class	Nominal Composition	Remarks
PHOTOFLASH POWDERS			
I	—	34% Magnesium 26% Aluminum 40% Potassium Perchlorate	Used at start of World War II in M46 Photoflash Bomb
II	A	60% 50/50 Magnesium-Aluminum Alloy 40% Potassium Perchlorate	Developed because of shortages at start of World War II of Aluminum and Magnesium Powder
	B	45.5% 50/50 Magnesium-Aluminum Alloy 54.5% Barium Nitrate	Later development led to substitution of Barium Nitrate for Potassium Perchlorate
III	A	40% Aluminum, Class C 30% Potassium Perchlorate 30% Barium Nitrate	
	B	Same as III-A except that the Potassium Perchlorate is coarser	
IV	—	80% Calcium 20% Sodium Perchlorate	Experimental Efficiency at 100,000 feet is 45.7×10^3 candlesec/g
SPOTTING CHARGES			
—	—	30% Atomized Aluminum 10% Flake Aluminum 60% Barium Nitrate	Developed to give short time to peak but with less brisance than photoflash powders

the light produced in the best 40 milliseconds, CPS_{40}). The duration of the flash increases as the cube root of the charge weight, while the peak intensity increases as the two-thirds power of the charge weight.[69,70,71] The efficiency and light output for a given weight of charge, therefore, decrease with charge weight.

6-4.5.2 Composition

As indicated in Table 6-22,[66] aluminum and magnesium are the best fuels for use in photoflash mixtures at low altitudes.[18,72] While atomized magnesium gives higher luminous intensities than other fuels in consolidated illuminating compositions, it has been found that atomized aluminum gives better results in nonconsolidated illuminating compositions.

Thermodynamic data for stoichiometric mixtures of aluminum and various oxidizing agents are given in Table 6-23.[73] The trend is similar to that for consolidated illuminants. (See Paragraph 6-3.5.1.) As the molecular weight of the oxidant increases, the aluminum content of the stoichiometric mixture decreases so that the heat of reaction also decreases. Of the oxidizers listed in this table, potassium perchlorate produces the highest heat of reaction with atomized aluminum. Luminosity values for various nitrates with atomized aluminum and atomized magnesium are given in Table 6-24. As indicated by this table, which is



XM101 Spotting Projectile

Figure 6-39. Typical 20 mm Spotting Round

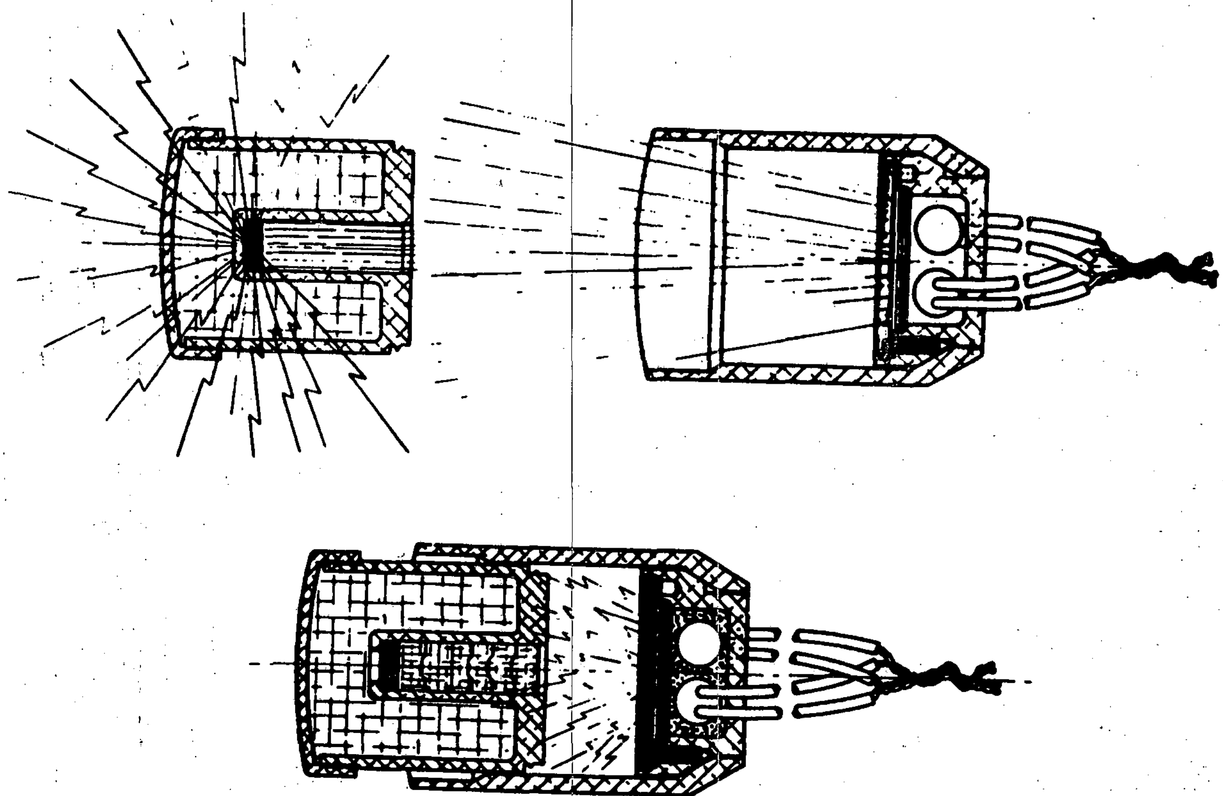


Figure 6-40. Photoflash "Daisy" Cartridge

for fuel-rich compositions, the light output of stoichiometric mixtures are relatively low; and alkaline earth metal nitrates are much more satisfactory than alkali metal nitrates in nonconsolidated illuminating compositions.

For dust-type bombs, there are marked differences in behavior of flake aluminum, atomized magnesium, and atomized magnesium-aluminum alloys. Atomized aluminum is difficult to ignite and has not been used efficiently in metal dust photoflash bombs. Flake aluminum, which requires a weight of burster approximately equal to that of the dust, produces a flash of relatively short duration and a rapid time to peak. Atomized mag-

TABLE 6-22
LUMINOSITY CHARACTERISTICS AT SEA LEVEL OF PHOTOFLASH COMPOSITIONS CONSISTING OF HIGH-ENERGY FUELS IN STOICHIOMETRIC AND FUEL-RICH COMBINATIONS WITH POTASSIUM PERCHLORATE

Fuel	Type of Composition[a]	Peak, 10^6 candles	Time to Peak, msec	Integral Light, 10^3 candlesec, (1/10 max)	Duration, msec		Efficiency, 10^3 candlesec/g Fuel	Increase in Efficiency, %
					1/10 max	Total		
Aluminum	S	41	1.2	147	9	14	10.3	35
	X	41	1.7	226	11	16	13.8	
Magnesium	S	18	1.2	142	16	24	10.0	15
	X	20	2.3	189	17	25	11.5	
Zirconium	S	38	0.7	92	7	14	2.8	147
	X	55	0.9	278	11	23	6.9	
Titanium	S	18	0.4	65	9	15	4.9	4
	X	16	1.3	80	12	21	5.1	
Calcium	S	12	1.2	75	13	16	5.7	30
	X	13	1.7	115	15	19	7.4	
Boron	S	0.5	23.0	18	68	89	3.5	85
	X	2	14.3	51	55	92	8.5	
Silicon	S	Did not ignite						
	X	Did not ignite						

[a] S = Stoichiometric, X = 14% excess fuel.

nesium, which requires a much smaller burster, gives a flash of much longer duration and has a longer time to peak. The magnesium alloys are intermediate in their behavior. The difference in the metal dust-to-burster ratio may be due to the relative ignitibility of the metal fuels. Powdered magnesium is easier to ignite than powdered aluminum; as a consequence, atomized aluminum has not been used efficiently in a metal dust bomb. The longer time to peak and flash duration of magnesium can be explained by the reaction between magnesium and nitrogen which precedes the reaction with oxygen.

Small amounts of additives, principally metals and silica gels, have been tried to increase the light output from photoflash devices. Results, in general, indicate that these additives do not increase the output of those photoflash items which are near optimum. Conflicting results have been obtained. Some earlier investigators obtained results which indicated improvement with some additives.[18]

6-4.5.3 Particle Size

Much of the research and development concerning photoflash compositions has centered around the determination of the optimum particle size and shape. While it has long been known that the average particle size and particle size range are important parameters in determining the luminosity characteristics of pyrotechnic flash mixtures,[18] detailed relationships were difficult to establish until methods became available to classify

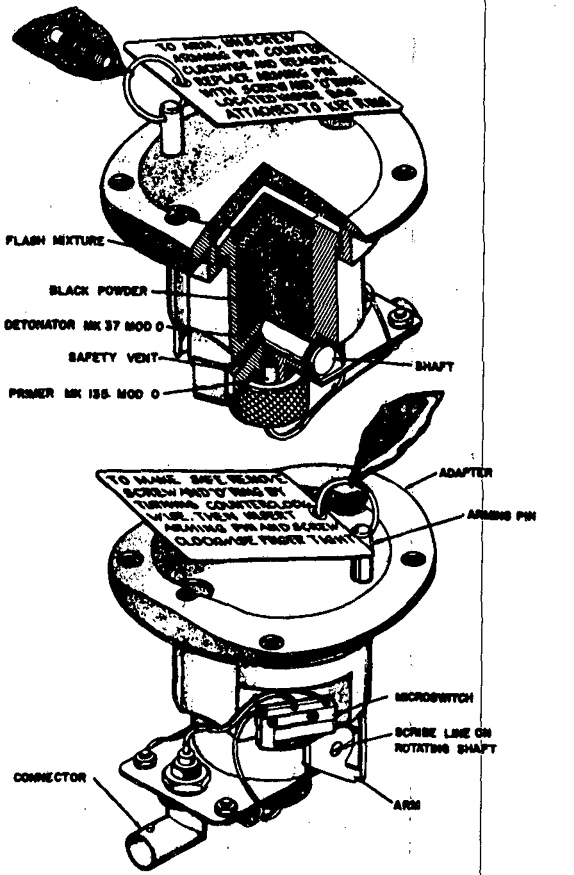


Figure 6-41. Typical Flash Charge for "Indication of Functioning"

TABLE 6-23
THERMODYNAMIC DATA FOR STOICHIOMETRIC MIXTURES OF OXIDIZING AGENTS AND ATOMIZED ALUMINUM

	Stoichiometric Ratio	*Calculated Heat of Reaction, Cal/g*
Sodium nitrate	65.4/34.6	1955
Potassium nitrate	69.2/30.8	1766
Strontium nitrate	70.2/29.8	1899
Barium nitrate	74.4/25.6	1598
Potassium perchlorate	65.8/34.2	2529

the fuel and oxidant powders into narrow particle size ranges.

For potassium perchlorate-aluminum (60/40 by weight) flash compositions, it was found that only systems in which the aluminum was in the 22 ± 8 micron particle size range would produce enough light for pyrotechnic applications.[74] Regardless of the oxidizer size, system containing coarser aluminum —8.4-40 microns and 24-62 microns—did not produce a usable amount of light. When the aluminum particle size was held constant, decreasing the oxidant particle size resulted in an increased efficiency (candle seconds per gram) at both sea level and at 80,000 feet simulated altitude. (See Figure 6-46.) At high altitude, the peak and integral light intensity vary similarly. At sea level, however, the composition with the coarse oxidizer produced the highest peak and integral light intensity, due to the greater tapped density with the coarse oxidizer fraction, so that a greater sample weight could be loaded into the test cartridge.

The marked differences in the behavior of the dusts used in dust-type photoflash bombs (Paragraph 6-4.5.2) result in the existence of an optimum particle size for each metal or alloy and each method of dispersion.[73] Excessively large particles will not ignite after dispersal. Efficiency tends to decrease, in the case of magnesium and magnesium-aluminum alloys, if there is too large a percentage of fines in the dust. As a consequence, the use of "run of the mill," less than 100 mesh, atomized magnesium is preferable to the use of mixtures containing a large amount of 325 mesh fine particles.[16]

In order for the diameter of the burst produced by dust-type photoflash bombs to be as large as observed experimentally, calculations indicate that the metal dust particles must "clump" together (possibly due to the pressure produced by the explosive burster) in fairly large particles, at least 250 microns in diameter. These "clumps," due to air-drag breakup as they move through the air, leave small particles (particles having the initial size distribution of the metal dust) which burn in the air.[18]

6-4.5.4 Cloud Shape

Since most photoflash bursts are essentially spherical in shape and essentially opaque to visible radiation, the amount of light radiated is proportional to the square of the burst radius, provided,

TABLE 6-24
LUMINOSITY VALUES OF VARIOUS OXIDANTS WITH ATOMIZED ALUMINUM AND ATOMIZED MAGNESIUM TESTED IN M112 PHOTOFLASH CARTRIDGE

Oxidant	*Peak Intensity, 10^6 Candles*	*Time to Peak, msec*	*Total Integral Light, 10^6 Candle-Seconds*
		Aluminum Compositions	
Sodium nitrate	Burned without detonation		
Potassium nitrate	Burned without detonation		
Strontium nitrate	124	3	1.61
Barium nitrate	139	3	1.64
		Magnesium Compositions	
Sodium nitrate	4	—	—
Potassium nitrate	Failed to ignite		
Strontium nitrate	21	5	0.33
Barium nitrate	42	5	0.65

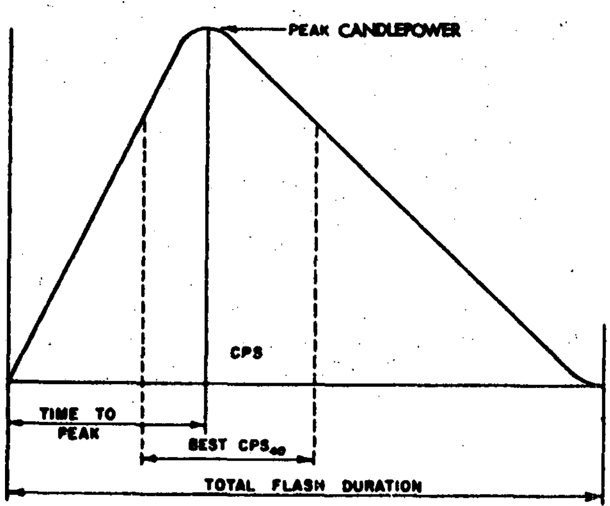


Figure 6-42. Typical Time-Intensity Curve

the temperature of the surface of the burst remains constant. Since the volume of the sphere is proportional to the charge weight, and the maximum temperature is limited to about 3000°C, the peak intensity should, as has been verified experimentally (Paragraph 6-4.5.1), vary as the charge weight to the two-thirds power. The efficiency of the larger charges is, therefore, less than that of the smaller charges but could be increased considerably by enlarging the effective surface area of the burst. Theoretically, an optimum system, as long as the temperature remains high, consists of an infinite number of infinitesimally small point sources.[75]

Line photoflash charges, as well as a large number of small photoflash charges have been attempted with some success. Both methods, which effectively increase the amount of radiating area for a given charge weight, are difficult to use practically.[18] As a result of recent improvements in aerial photographic techniques and equipment, which permit the utilization of light over longer periods of time (up to 250 milliseconds), pellets of pressed illuminating composition have been used in place of short duration photoflash charges. Results indicate that efficiencies are much greater than those obtained with photoflash compositions.[75]

6-4.5.5 Bursters and Igniters

A great many explosives have been tried (Table 6-25) as bursters in dust-type photoflash bombs. In general, the most powerful or brisance buster seems to perform best. RDX is better than tetryl which, in turn, is better than TNT, other conditions being equal. Aluminized explosives at optimum

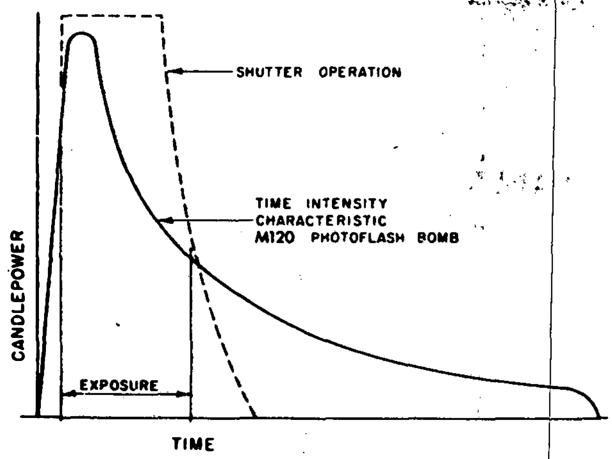


Figure 6-43. Synchronization of Shutter

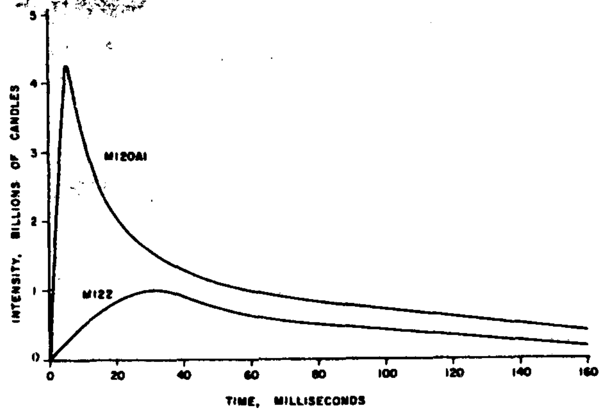


Figure 6-44. Time-Intensity Curves for M120A1 Flash Powder and M122 Dust Photoflash Bombs

concentrations have greater power than the pure explosive and, therefore, perform better as bursters.[18]

As has been indicated, there are marked differences in the behavior of flake aluminum, atomized magnesium, and atomized magnesium-aluminum alloys when dispersed and ignited as a dust cloud. Flake aluminum requires a weight of burster approximately equal to the weight of the metal dust. Atomized magnesium requires much less weight, approximately 1/100 of the weight of the metal dust.[73] The maximum radius of a magnesium dust flash depends, approximately, on the cube root of the dust-to-burster ratio for the lower ratios and on a somewhat lower power at the higher dust-to-burster ratios. At a constant dust-to-burster ratio, the radii of magnesium dust flashes increase, roughly, as the cube root of the quantity of dust. In general, for magnesium and magnesium-aluminum alloys, an increase in the dust-to-burster ratio results in an increase in time to peak, an increase in flash duration, along with an increase in integrated light values, and, to a lesser extent, an increase in light intensity. Because of the large amounts of burster required for flake aluminum, variations in the dust-to-burster ratio within the useful ranges seem to have little effect.

Other factors—including shape of the burster, loading techniques, and confinement—have been studied. Most dust-type bombs that have been studied use a cylindrical burster or a truncated cone. The method used to load a burster did not appreciably influence the output of the dust bomb. Centrally located bursters, all factors considered, gave results comparable to those for any other location. The shape of a relatively small amount of explosive in an essentially nonreacting metal dust should have little influence except to change the center of the gas bubble formed. (See Paragraph 6-4.4.2.)[68]

For a reactive photoflash mixture where the reaction contributes to the growth of the gas bubble, the effect of location, shape, and amount of initiator are important. The use of an initiator too powerful for a particular case and composition might cause too rapid expansion of the gas bubble, resulting in case rupture before a desirable initiation of the photoflash mixture. For a long column of flash composition with an initiator in one end, a stage can be reached where reaction in the photoflash mix will propagate through the mixture resulting in some measure of independence from the mode of ignition.[18,68] During this process, the case must continue to maintain confinement in order to have adequate ignition of the balance of the photoflash mixture.

6-4.5.6 Confinement

The characteristics of the case surrounding a reactive photoflash mixture affect the amount of time available for ignition of the mixture as well as the way the mixture is released and disseminated. A case of excessive strength, requiring an appreciable amount of energy to rupture, may divert

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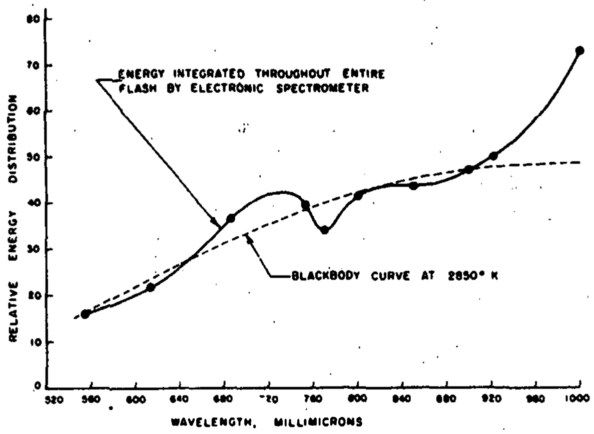

Figure 6-45. Spectral Energy Distribution Curve of M120 Photoflash Bomb

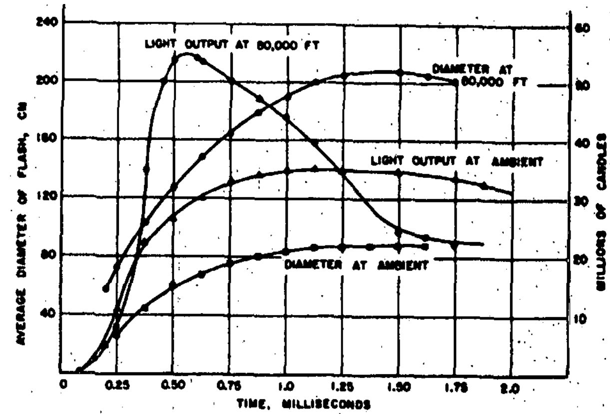

Figure 6-47. Size and Light Output of Flash Cloud vs Time

sufficient energy to reduce the light output. Too thin a case may allow the mixture to be released before adequate ignition has taken place, thus reducing the effectiveness of the flash. This effect, which would be emphasized at low ambient pressures, was illustrated in tests conducted with metal and plastic cases. With the metal case, the expected light output was obtained at ambient conditions and 80,000 feet and with the plastic case at ambient conditions; however, a sharp drop occurred for plastic cases at 80,000 feet. Variations in thickness within narrow limits for metal cases were found to cause negligible changes in light output.[68]

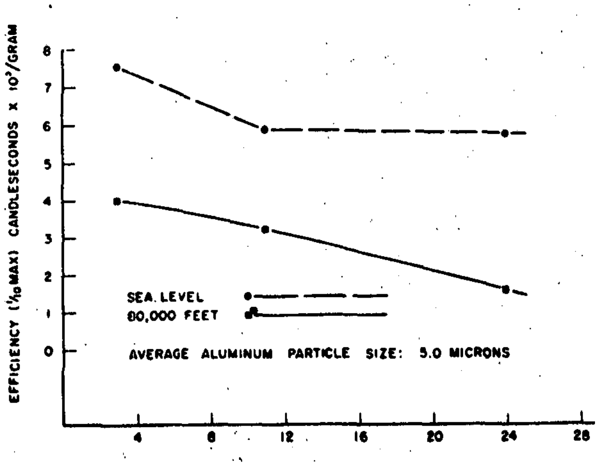

Figure 6-46. Effect of Particle Size of Potassium Perchlorate on Luminous Efficiency of 60/40 Potassium Perchlorate-Aluminum Compositions

TABLE 6-25
HIGH EXPLOSIVES TRIED AS BURSTERS IN FLASH BOMBS

Nonmetallized	*Metallized*
Comp. A-3	Al/$KClO_4$/cellulose nitrate, 49/49/2
Comp. C	Comp. A-3/Al,80/20
Gunpowder	Comp. B/Al,80/20
Photoflash Powder	HBX-3
Type III, Class C	HBX-6
Primacord	Minol 2
Pyrotechnic Compn.	RDX/Al/wax
RDX	RDX/TNT/Al, 42/40/18 (Torpex 2) 20/50/30
RDX/TNT	RDX/TNT/Al/Carbon, 20/55/25/2.5
RDX/TNT, 60/40	RDX/Al/PIB, 78.5/20/1.5
Sodatol	Tetryl/Al
Tetryl	TNT/Al
Tetryl/TNT, 30/70	Tritonal: TNT/Al 70/30 75/25 80/20
TNT	

For dust-type photoflash bombs, the casing material has a relatively unimportant influence on the light output. The thickness of the case has a limited but not critical effect on the output, especially with large bursters.[76,77]

TABLE 6-26
LUMINOSITY CHARACTERISTICS OF PHOTOFLASH COMPOSITIONS CONSISTING OF HIGH-ENERGY FUELS IN STOICHIOMETRIC COMBINATION WITH POTASSIUM PERCHLORATE*

Fuel	Composition Weight, g	Peak, 10^6 candles	Time to Peak, msec	Integral Light, 10^3 candlesec, (1/10 max)	Duration, msec		Efficiency, 10^3 candlesec/g	
					1/10 max	Total	Composition	Fuel
				Sea Level				
34% Aluminum	42	41	1.2	147	9	14	3.5	10.3
41% Magnesium	35	18	1.2	142	16	24	4.1	10.0
57% Zirconium	58	38	0.7	92	7	14	1.6	2.8
41% Titanium	33	18	0.4	65	9	15	2.0	4.9
58% Calcium	23	12	1.2	75	13	16	3.3	5.7
17% Boron	31	0.5	23.0	18	68	89	0.6	3.5
29% Silicon	35		Did not ignite					
				100,000 Feet				
34% Aluminum	42	49	1.3	103	7	14	2.5	7.3
41% Magnesium	35	16	0.5	10	1.2	33	0.3	0.7
57% Zirconium	58	65	0.7	92	3	11	1.6	2.8
41% Titanium	33	29	0.6	49	4	13	1.5	3.7
58% Calcium	23	26	0.5	176	21	29	7.7	13.3
17% Boron	31		No deflection					
29% Silicon	35		Did not ignite					

*Test vehicle, M112 charge case reduced to 1.72-inch length.

6-4.5.7 Ambient Pressure

As indicated by the data in Table 6-26 the light output of most possible photoflash mixtures is less at an altitude of 80,000 feet than at sea level. Of the high energy fuels evaluated, aluminum and magnesium were most efficient at sea level and calcium was most efficient up to 100,000 feet.[66] As the boiling point and extent of dissociation of the reaction products depend on the ambient pressure, the final flash temperature will decrease with increasing altitude. The radiation produced by most photoflash items is continuous (see Paragraph 6-4.4.1.2) approaching that of a graybody with a high emissivity and lower light values obtained. Some compensation for this loss of light results because the flash diameter at altitude (Figure 6-47) is greater than at sea level.[68]

The effectiveness of photoflash mixtures containing calcium depends on the formation and energy content of discrete bands.[78] The phenomenon of increasing light output observed with compositions containing calcium metal, calcium alloys, calcium perchlorate, and calcium nitrate also results when adding an inert calcium salt such as calcium oxide or calcium fluoride to a composition producing a high temperature such as aluminum-potassium perchlorate. The magnitude of the increase in light output, however, is considerably less than for other calcium-containing compositions.[66]

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mixture of pitch, tallow, black powder, and saltpeter. The obscuring power of the smoke was due to incomplete combustion of the solid particles in the pitch. Screening smoke was used on a large scale by the Canadians in their attack on Messines Ridge in September 1915. During the following year, the use of smoke continued to increase as its value became apparent to all of the major belligerents.[1]

Both red and white phosphorus were soon introduced as smoke-producing materials. White phosphorus proved to be the more efficient of the two and was by far the most efficient smoke-producing material introduced during World War I. Sulfur trioxide was the next most efficient smoke-producing material used, in spite of the fact that humid air was required to form the sulfuric acid fumes. Other materials which produce sulfuric acid fumes on contact with humid air, such as oleum, chlorosulfonic acid, and sulfuryl chloride, were also widely used. The two latter materials also produced hydrochloric acid fumes. Metallic chlorides, including tin tetrachloride (British K.J., French Opacite), titanium tetrachloride (German F-Stoff; United States FM), and silicon tetrachloride, were also used.

Another group of materials, producing the so-called zinc smokes, were basically mixtures of zinc dust and an organic chlorine-containing compound. The Berger mixture, used by the French during World War I, was composed of zinc dust, carbon tetrachloride, zinc oxide, and kieselguhr. An improved mixture was developed in 1917 by the U. S. Bureau of Mines and was known as the BM Mixture. This mixture consisted of zinc dust, carbon tetrachloride, sodium chloride, ammonium chloride, and magnesium carbonate.

The introduction of military aircraft, especially bombers which could attack important rear-area targets, created a definite need for large-area smoke screens for protection. Consequently, much of the effort between the two World Wars was directed toward developing techniques for producing these large-area smoke screens, including the use of aircraft for this purpose.[4,5] At the beginning of World War II, however, neither the United States nor Great Britain had a satisfactory material or a suitable method for producing large-area screens.

The smoke munitions available in 1940 included projectiles, bombs, smoke pots, grenades, and airplane spray tanks, which were sufficient to enable ground tactical units to conceal their movements by laying curtains of smoke across the battlefront. The tactical employment of small, smoke-producing munitions was established as a result of actual experience in field maneuvers and demonstrations. The principal screening materials available included sulfur trioxide-chlorosulfonic acid (FS), a liquid solution for use in projectiles and airplane spray tanks; hexachloroethane-metallic zinc mixture (HC), a solid mixture used in burning-type munitions such as grenades and smoke pots; and white phosphorus (WP), used in grenades, projectiles and bombs. These materials were superior to similar materials developed and used during World War I.

The effectiveness of German air operations against British cities during 1940-41 was considerably reduced through the use of large-area smoke screens which prevented accurate aiming. The British protected important industrial centers with smoke pots of an oil-burning type similar to the smudge pots used in United States orange groves. Lines of smoke pots were laid out in such a manner that the vital area was screened under any wind direction. The operation of this type of stationary smoke pot line required an extensive supply system since all important areas needed protection. As a result, the British developed truck-mounted mobile generators, the most suitable of which was known as the "Haslar" which produced a gray-brown smoke by burning and vaporizing crude oil.[4,5]

In the United States, the Defense Department and the National Defense Research Committee, along with several universities and industrial concerns, cooperatively embarked on a research program to produce large-area smoke screens. Early in 1942, the optimum particle size for a hydrocarbon smoke was determined and mechanical smoke generators were developed to produce this type of screen.[6] Work on smoke pots based on the venturi principle was started at this time using fuel blocks to vaporize volatile materials; however,

these devices were not fully ready for production during World War II.

The smoke-producing materials such as WP, FS, and HC had disadvantages which at times, limited their usefulness in World War II. All of the smokes produced from these materials were irritating. FS smoke was corrosive in the presence of moisture. WP smoke tended to rise rapidly, or to pillar, due to the heat given off by the burning phosphorus. HC, and similar smoke compositions, produced zinc chloride which was toxic. In spite of the disadvantages, these items were used, along with the newly developed, mechanical smoke-producing devices, in advancing the strategic and tactical use of smoke during World War II. For the first time, large areas, including whole cities, could be screened from aerial observation for relatively long periods of time.[4,5]

Screening smoke again proved to be of value in the Korean action in which the United Nations' Forces operated without the benefit of air superiority for much of the time. Hence, large-area screens were employed to protect vital port areas as well as forward combat areas.[7] In addition, much of the Korean action was a struggle for dominating terrain, and smoke was constantly used in relatively small-scale operations. Colored smoke was also used for screening personnel withdrawal operations because it persisted longer than the white phosphorus smoke normally used for this purpose.[1,6,8]

7-1.2 SIGNAL SMOKES

The need for methods of signaling when neither hand signal nor flag is visible, nor the sound of voice or horn is audible, has long been recognized. Smoke signals have been used for this purpose since ancient times. However, the thick haze of black powder smoke which enveloped battlefields virtually eliminated smoke as a signaling agent for a time. The introduction of smokeless powder again made smoke signals a valuable method of communication in military operations. In spite of the many improvements in communications methods, signal smoke continues to have an important place in modern warfare.

Prior to World War I, a limited number of pyrotechnic items, mainly colored flares, were used by the Services. Little information on the manufacture and application of colored smoke signals was available in the United States at the beginning of World War I due, mainly, to the curtailment in fireworks manufacture. Investigations were started by various civilian and military agencies. Various types of smoke signals—including both parachute and nonparachute rockets, rifle grenades, Very pistol cartridges, hand grenade signals for aviators, submarine recognition signals, and smoke pots for ground use—were developed in a variety of colors. Inasmuch as the American Expeditionary Forces were to operate in a sector held by the French Army, it was found expedient to adopt the entire French Army system of pyrotechnics.

The French used colored smoke signals which consisted of red and yellow smokes in signal parachute rockets, rifle grenades, 25 mm and 35 mm Very pistol cartridges, and a messenger signal. The only French smoke manufactured in the United States was yellow smoke, since this item could be produced from available ingredients; the other colored smokes, such as red, could not be manufactured because necessary dyestuffs were in short supply at that time. The United States did not develop mortar or artillery projectiles producing colored smoke during World War I.

The British Army also recognized the need for colored smoke signals and developed a number of such munitions early in World War I. Red, yellow, blue, and violet smokes were developed for use in rifle grenades (with or without parachutes), in Very pistol cartridges, and in 3-inch mortar projectiles. A red and blue smoke filling for the 4.5-inch projectile was developed for artillery spotting and aviation signaling. Dummy drop bombs or subcaliber bombs containing colored smoke fillings were developed for training purposes. By the close of World War I, the Allies succeeded in developing experimental colored smoke rifle grenades as well as rockets and Very cartridges in a variety of colors. They also made some use of colored smoke for artillery spotting. Virtually no information is available concerning the use of colored smoke by the Germans and Italians during World War I.

Although the research and development effort in the United States proceeded at a reduced rate

in the period between World Wars I and II, a considerable number of munitions for producing colored smoke were developed. Included among these items were colored smoke hand and rifle grenades, canisters containing colored smoke fillings for various calibers of projectiles, colored streamer smoke bombs, colored smoke markers for aerial delivery containers, and colored bursts for the 4.2-inch chemical mortar projectile. All of these were produced in a variety of colors. The British Army also developed colored smoke rifle and hand grenades, and colored smoke fillings for most of their artillery projectiles. The German Army limited their colored smoke signals to various small hand signals.

Extensive use of signal smoke in World War II and the Korean Conflict proved that the use of colored smoke for signaling purposes has an important place in the communications system of modern warfare. Four colors—red, green, yellow, and violet—were found to be the most suitable. Smokes were also of value in marking a specific operations area or target. They also played an important part in antisubmarine warfare and in air-sea rescue operations. In many instances, especially in the Korean Conflict, the use of pyrotechnic signals, including smoke, was much faster and more effective than more modern communications methods when the tactical situation was degenerating.[9]

7-1.3 TRACKING AND ACQUISITION SMOKES

Smoke has been found to definitely complement the observance of tracer projectiles and, more recently, has been used as a space vehicle tracking aid. Tracer bullets, while developed as a light-producing device for improved aim and fire control for automatic weapons, emit distinct amounts of white smoke which is composed essentially of metal oxide particles. Under certain atmospheric conditions, such as firing into bright sunlight, the smoke trail is easier for a gunner to follow than a red flame tracer, although the flame tracer is the best under most other conditions. In 1923, studies were undertaken to develop a smoke tracer. It was soon apparent that attempts to increase the volume of the smoke trail along the trajectory resulted in a decrease in the flame color and intensity. Since the flame tracer was considered most important, the work was not pursued. After World War II, a requirement for smoke tracers was reestablished, and improved smoke tracers were developed based on the use of organic dyes,[10] the best of which were of the anthraquinone series producing orange-red smoke. These smoke tracers were developed primarily for training pilots to improve their gunnery score with wing-mounted guns. Due to the pilot's extreme forward position in the aircraft, flame tracers coming from the wing guns in the rear were difficult to pick up and follow visually as they passed. Smoke tracers, on the other hand, left a lingering trail which was easier to sight and point at the target. However, since they could not be seen readily at night they were not considered all-purpose tracers and, consequently, did not become standardized.

In 1950, development of spotting bullets as an additional aid for fire control and target acquisition was undertaken.[11] A smaller caliber spotting bullet was designed to match the trajectory of the major round at the critical range. Upon impact with the target or nearby, the spotting bullet exploded to give flash and smoke. Since the flash was of extremely short duration (30 to 50 milliseconds), the smoke puff became of greater importance because it rose and lingered over the point of impact for a longer period so that the gunner could readily correct his aim. This development resulted in the standardization of the caliber .50 M48 combination spotter-tracer round and the development of a new family of spotting rounds.

Another use for the smoke-producing devices resulted from the increasing speed of air or space vehicles which were developed after World War II. In order to assist test personnel in the optical tracking of these vehicles, it was necessary to develop smoke-producing tracking aids, some of which were required to function at extremely high altitudes.

7-2 PROPERTIES OF SMOKE

The value of a military smoke, whatever its use, is related to the scattering, reflection, and absorption of incident radiation by small suspended particles. These properties are associated with the

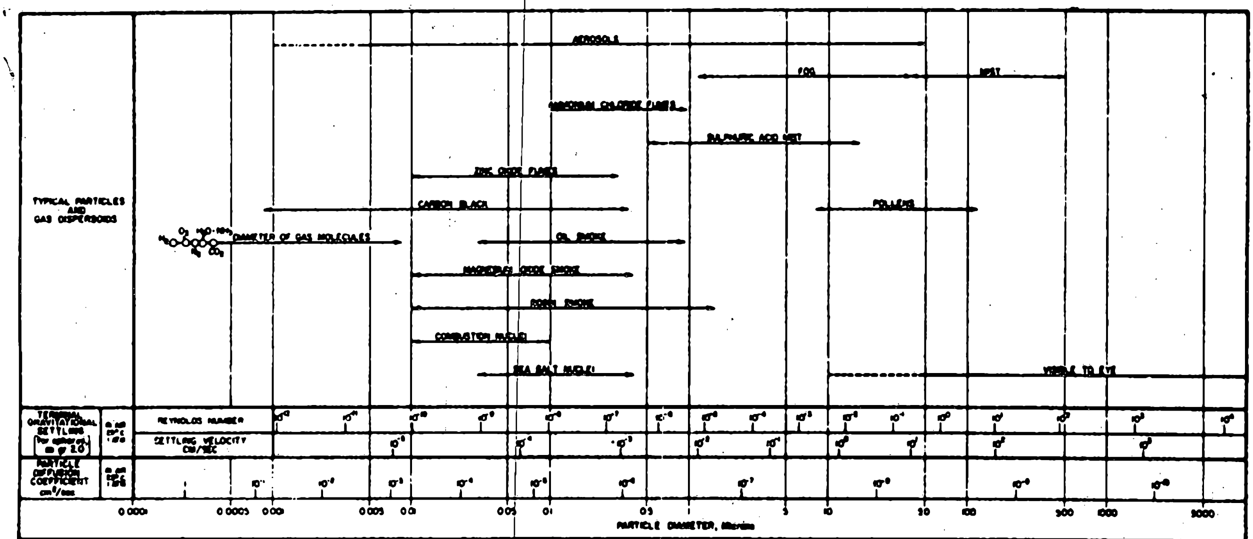

Figure 7-1. Approximate Size Range of Airborne Particles

number, size, and nature of the suspended particles. The number of particles, their size, and initial behavior depend upon the smoke agent, the particular munition, and the method of release. The density, persistency, and subsequent behavior of the smoke cloud also depend on meteorological conditions, such as humidity, wind speed, wind direction, and air stability.

7-2.1 PROPERTIES OF PARTICULATE CLOUDS[8,12]

The classification of types of suspensions in terms of their nature, origin, and particle size has not been completely successful due to their indefinite characteristics and because of the differences, not always clear-cut, between descriptive terms in scientific and common usage. A gaseous suspension of liquid or solid particles the diameter of which is less than 100 microns is commonly called a particulate cloud. There are three broad classes of particulate clouds: (1) dusts, (2) mists, and (3) smokes. If the particles in any particulate cloud are less than approximately 10 microns in diameter, they are called aerosols. The term aerosol was introduced to cover only fine, aerial suspensions. It has, however, been applied in recent years to almost any aerial suspension of particles. In some cases, especially in the United States, the term aerosol is used instead of particulate cloud.

Dusts are particulate clouds made up of solid particles formed by the mechanical disintegration of matter. The diameter of the particles in a dust range from about 0.1 micron to greater than 100 microns.

Mists are gaseous suspensions of liquid droplets produced by the condensation of a vapor or atomization of a liquid. Mists, especially those occurring naturally, consist of relatively large particles ranging in size from around 5 microns to larger than 10 microns. If the concentration of droplets is great enough to interfere with vision, it is called a fog.

A smoke is a suspension in a gaseous medium, such as the atmosphere, of small particles which have a relatively low vapor pressure and which settle slowly under the influence of gravity. Although smokes are often characterized by their mode of formation, the main criterion is one of particle size. While, at one time, only clouds formed by combustion and destructive distillation were classified as smokes, at present any gaseous suspension of particles ranging in size from approximately 0.01 to perhaps 5.0 microns in diameter, and which cannot be classified as a dust or mist, is considered to be a smoke. In many cases the smoke particles are aggregates of many extremely small, primary particles. Carbon smokes, for example, are composed of extremely small,

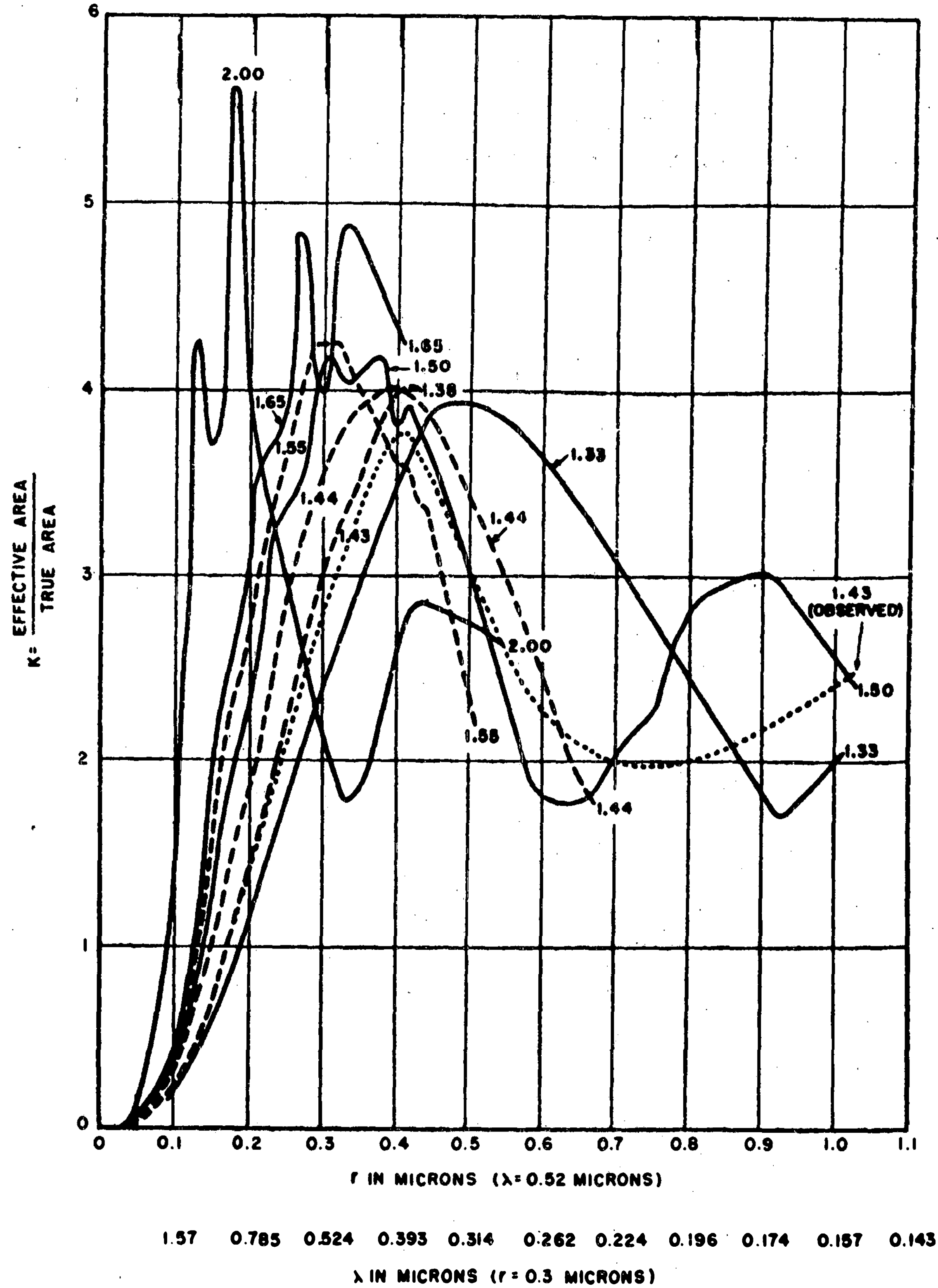

Figure 7-2. Scattering by Spherical Particles With Indicated Refractive Indexes

primary particles of approximately 0.02 micron in diameter which coagulate into irregular filaments that may reach a length of several microns. In Figure 7-1 is shown the approximate particle size ranges for typical airborne particles.

7-2.1.1 Optical Properties of Particulate Clouds

Particles suspended in a gaseous medium scatter, reflect, and absorb radiation in a manner which depends on the nature, size, and shape of the particle, and the wavelength of the incident radiation. These factors, in turn, determine the effectiveness of a smoke for screening and its visibility when used for signaling or similar purposes.

The scattering of light by a particle can be treated as the interaction between the electromagnetic waves and the particle. When light strikes a particle which is comparable in size to, or smaller than, its wavelength; reflection and refraction, in their normal sense, no longer occur. Interaction between the radiation and particle results in energy being removed from the wave front. Some of this energy is degraded to heat but much is re-radiated as scattered radiation. Each particle becomes, in effect, a self-luminous source.

The theory of scattering by spherical particles was developed from Maxwell's equations by Gustave Mie.[18] For spherical particles which are small compared to the wavelength of light, this theory gives results which are in complete agreement with the results obtained from the less-general Rayleigh theory which states that the amount of radiation scattered is inversely proportional to the fourth power of the wavelength. As the particle radius increases in size to approximately the wavelength of the light, the scattering becomes a complex function of the particle radius, the refractive index of the particle, and the wavelength of the incident light. The scattering coefficient, i.e., the scattering index, is an extremely complex function of the parameter r/λ, where r is the radius of the particle and λ is the wavelength of the incident light, and exhibits one or more peaks before approaching the limiting value of 2.0 as is shown in Figure 7-2. As the refractive index of the particle increases, the peak in these curves moves toward smaller radii particles. For screening smoke made from fog oil which has a refractive index of 1.50, the maximum scattering of vehicle light will occur when the droplets are about 0.3 micron in diameter.

The angular distribution of the scattered light is also a function of r/λ. For Rayleigh scattering by small particles, the forward and backward scattering is the same. With an increase in the particle radius, the forward scattering becomes much greater. For a particle whose radius is equal to or greater than the wavelength of light, this factor may be 1000 or more in favor of the forward scattering.

Smoke clouds, which have a distribution of particle sizes, exhibit the scattering which would be observed for a mixture of a large number of different uniformly sized smokes mixed in varying proportions. No completely satisfactory analysis of the amount of scattering that may be expected from such a polydispersed smoke cloud has been made.

The theoretical treatment of the scattering of light by particles which also absorb is a difficult problem, especially when absorption is selective. When the incident light is white, the scattering by each of the particles will remove some of the light selectively absorbed so that the light finally scattered by the cloud will be colored.

7-2.1.2 Properties of Particulate Clouds Affecting Their Stability

Smoke clouds and other particulate clouds are essentially unstable and will eventually disappear with time due to: (a) motion of the particles, (b) evaporation and/or condensation, and (c) coagulation and agglomeration.

7-2.1.2.1 Motion of Smoke Particles

Movement of smoke particles under the influence of gravity and as a result of random bombardment by gas molecules (Brownian motion) may cause particles to disappear by sedimentation or diffusion. Sedimentation effects are important for particles one micron and larger, while diffusion effects are important only for much smaller particles.

7-2.1.2.1.1. Sedimentation

An individual particle settling under the influence of gravity will reach a terminal velocity

when the aerodynamic drag on the particle is equal to the effective weight of the particle. If the particle is a rigid sphere which is large with respect to the mean free path of the gas, but not so large that inertia effects are important, Stokes' Law is applicable, and the terminal velocity v is given by:

$$v = \frac{gd^2(\rho - \rho')}{18\eta} \qquad (7\text{-}1)$$

where d is the diameter of the particle, ρ is the density of the dispersed phase, ρ' is the density of the gas, η is the viscosity of the gas, and g is the acceleration due to gravity. Particles which are small with respect to the mean free path of the gas fall somewhat more rapidly than this equation indicates, while large particles settle somewhat more slowly.

The rate of sedimentation for some particles is given in Table 7-1. It is to be noted that the sedimentation rate of a screening smoke which has a particle radius of 0.3 micron is about one mile per year.

TABLE 7-1
TERMINAL VELOCITIES AND DIFFUSION COEFFICIENTS OF RIGID SPHERES OF UNIT DENSITY IN AIR AT 760 mm Hg PRESSURE AND 20°C

Diameter, microns	*Velocity, cm/sec*	*Diffusion Coefficient, cm²/sec*
0.1	8.71×10^{-5}	6.84×10^{-6}
0.2	2.27×10^{-4}	2.02×10^{-6}
0.4	6.85×10^{-4}	8.42×10^{-7}
1.0	3.49×10^{-3}	2.76×10^{-7}
2	1.19×10^{-2}	1.28×10^{-7}
4	5.00×10^{-2}	6.16×10^{-8}
10	3.06×10^{-1}	2.41×10^{-8}
20	1.2	----
40	5	----
100	25	----

Nonspherical particles generally attain a lower terminal velocity; however, this effect is not completely predictable. If the smoke is heterogeneous, the particles will settle at different rates causing collisions between particles and resulting in coagulation or agglomeration of the particles.

7-2.1.2.1.2 Diffusion

Diffusion of particles due to Brownian motion results because the particles are impacted by the gas molecules of the suspension medium. The motion imparted to the smaller particles is greater than that imparted to the larger particles so that the amount of diffusion is inversely proportional to the diameter of the particles.[3] Diffusion effects are relatively unimportant for most particulate clouds of military interest.

7-2.1.2.2. Evaporation and Condensation

The evaporation rate for a given material depends on the difference between the vapor pressure of the dispersed material and the actual partial pressure of its vapor present in the air. At a given temperature, the vapor pressure of a liquid increases with the degree of curvature of its surface; this increase becomes marked as the droplet size decreases. Hence, a critical droplet exists for any temperature and vapor concentration. Droplets smaller than the critical size will evaporate because their vapor pressure is higher than the partial pressure in the vapor phase, while those larger than the critical size will grow as a result of condensation. The same considerations apply to the sublimation pressure of a small, solid particle.

7-2.1.2.3 Coagulation and Agglomeration

The process of continuous and spontaneous formation of larger particles is one of the striking characteristics of any particulate cloud and can be a major factor in the diminution of a smoke cloud; liquid particles coalesce while solid particles agglomerate when they collide. As this process continues, the smoke becomes coarser and finally settles out. It has been found experimentally that the rate of decrease of the number of particles, $-\left(\frac{dn}{dt}\right)$, is proportional to the square of the concentration n, or:

$$-\left(\frac{dn}{dt}\right) = Cn^2 \qquad (7\text{-}2)$$

where C is the coagulation constant. In integrated form:

$$\left(\frac{1}{n}\right) - \left(\frac{1}{n_o}\right) = Ct \quad (7\text{-}3)$$

where n_o is the number of particles at $t = 0$.

While it is difficult to calculate the exact degree of polydisperity, it can be shown that the probability of collision between particles of unequal size is greater than that between particles of equal size. Hence, polydisperse smokes coagulate faster than those which are monodisperse. Moreover, differential settling also increases the probability of collisions between particles of different sizes. The coagulation rate of smoke is increased by stirring, since eddies and swirls result in particles having a higher relative velocity which increase chances of collisions resulting in an increased coagulation rate.

7-2.2 TRAVEL AND PERSISTENCE OF PARTICULATE CLOUDS[8,12]

The behavior of a particulate cloud is strongly influenced by the diffusive properties of the atmosphere. For example, the persistence of screening smokes, which are composed of particles too small to fall out appreciably by Stokes' Law and which have too low a vapor pressure to evaporate, is almost completely dependent on meteorological factors which tend to dilute the cloud. The form of a particulate cloud in the atmosphere depends upon the location, type, and configuration of its source. When a cloud is emitted from a jet at a considerable velocity, mechanical turbulence and rapid mixing with the air results. This initial condition of turbulence disappears by the time the cloud has traveled a short distance from the generator. Also, the formation of particulate clouds of military interest is accompanied by sufficient heat so that the cloud as a whole will rise. As the cloud becomes more and more diluted with cooler air this effect will be less observable unless there is a very great initial rise in temperature, as is the case when smoke is produced by the burning of white phosphorus. (See Paragraph 7-3.3.2.1.)

The process by which smoke is diluted and mixed with air is called "atmospheric diffusion." This process is also termed "eddy diffusion" to distinguish it from molecular diffusion since eddy-like motions of from one to many feet in diameter are observed. The amount of atmospheric diffusion is indicated by the angle of rise and angle of spread of the cloud as it travels downwind from the source. The initial angles of rise and spread usually will be different than those measured farther away from the point of generation.

7-2.2.1 Meteorological Factors

While the initial behavior of a particulate cloud normally is due to the transient effect of the heat and turbulence resulting from the process by which the particulate cloud is generated, the behavior of the cloud at a distance from the generator depends on the meteorological conditions prevailing. The principal meteorological factors affecting travel of this type of cloud are wind speed, direction, turbulence in the lower atmosphere, and thermal gradients.

7-2.2.1.1 Wind Speed and Direction

To obtain a cloud concentration in an area from a limited number of stationary sources, a wind velocity of fixed speed and direction is desirable. Too high a wind speed requires an exorbitant rate of production in order to maintain proper coverage, while too low a wind speed requires excessive time to develop the cloud. If there is no wind, good results can only be obtained by producing the cloud from a moving vehicle such as a plane or boat, or by the projection of smoke generating munitions into the area. The latter method is feasible only in offensive operations. Conditions of very low wind speed are likely to be accompanied by sudden variations in the wind, carrying the particulate cloud into areas where it is not desired.

When a particulate cloud is emitted by a stationary generator in a steady wind, the plume travels downwind with the speed of the wind and the axis of the plume is parallel to the wind direction. The density of the cloud at any point downwind will be, in general, approximately inversely proportional to the wind speed.

7-2.2.1.2 Turbulence

Wind speed and direction are subject to rapid and violent fluctuation. This unsteadiness in wind

velocity and direction can be considered to be due to pulsations taking place in three directions; namely, in the general direction of the wind, and in horizontal and vertical directions at right angles thereto. The total of these pulsations in the different directions is a measure of the gustiness or turbulence of the atmosphere.

One obvious cause of turbulence is mechanical. The higher the wind velocity, the greater the turbulence, particularly over rough terrain. Over a smooth surface of water there will be no turbulence produced by mechanical causes at low wind speeds. Wind speeds greater than 10 to 11 knots, however, will produce waves which, in turn, produce mechanical turbulence in the lower air layers.

Another important factor in producing turbulence is thermal instability in the lower atmosphere. During the day in bright sunshine, the ground surface receives a great deal of heat from the sun and, since the earth is a poor conductor, the temperature of the surface will rise many degrees. The layer of air in contact with the ground is heated and, since it becomes lighter by expansion, the layer rises. Since the warm lower layer of air cannot rise everywhere uniformly, it must break through the upper cooler layers somewhat as bubbles burst upward through a liquid. The actual driving force is the weight of the cooler air, which settles toward the ground displacing the warmer, lighter air. These upward, convective currents cause the bumpiness of the air which is noticeable in an airplane. The passage of a warm or cold front may completely alter the temperature relation between the ground surface and air and produce stability or instability regardless of time of day or sky conditions.

7-2.2.1.3 Thermal Gradient

Stability conditions in the atmosphere are determined by the temperature gradient therein. If the temperature decrease with height is more than 1°C per 100 meters, the air will be unstable; i.e., the lower layer of air will tend to rise and continue to rise as long as this condition prevails. This is caused by the rising mass of air, expanding and cooling as it rises, becoming warmer and lighter than the surrounding air. If the decrease in temperature with altitude is between zero and 1°C per 100 meters, there will be no tendency for the air to rise because the air mass carried upward will become colder and heavier than the surrounding air. This decrease of temperature with altitude of 1°C per 100 meters is termed by the meteorologist the adiabatic lapse rate for dry air, and the degree of stability or instability of the atmosphere will depend upon the extent to which the temperature gradient departs in one direction or the other from this critical value. An extreme condition, when the temperature increases with altitude, is known as inversion, which causes extreme stability in the lower atmosphere. The meteorological factors described contribute to the degree of stability of the atmosphere which exerts a considerable influence on the performance of a smoke cloud. Extreme conditions of stability or instability will influence the effectiveness of the smoke cloud in a particular tactical situation.

7-2.2.2 Stability of Aerosol Clouds Under Various Meteorological Conditions

7-2.2.2.1 Stable Conditions

Under inversion conditions over smooth terrain such as calm water, the only tendency shown by a smoke cloud to rise and spread is due to the initial transient effect caused by the heat and turbulence produced by the smoke generator. The turbulence is quickly damped out but the heat produced may be sufficient to cause a very pronounced rise, as is the case with white phosphorus smoke munitions. In the case of oil smoke, where the amount of heat produced is small, the temperature of the smoke at any dilution is only slightly greater than the temperature required to produce a buoyancy sufficient to offset the increase in density caused by the presence of the smoke material. As the smoke rises, the temperature falls because of two effects; namely, further dilution with cool air, and adiabatic expansion due to a decrease in barometric pressure. Since, in an inversion, the temperature of the surrounding air increases with increasing altitude, an elevation is soon reached at which the smoke is stable, possessing a density identical with that of the surrounding air.

Oil vapor smoke is often observed to level off

at an elevation of approximately 100 feet under stable air conditions. Certain types of smoke exhibit an erratic behavior because of abnormal density. Examples of these are: (a) the smoke produced by burning oil in an orchard heater in which carbon particles and carbon dioxide gas are present, and (b) HC smoke in which large particles of zinc chloride and other heavy materials are formed. While a substantial amount of heat is produced in the formation of these smokes, much of it is quickly lost by radiation, particularly at night. Since the heat produced in the generation of the smoke will usually cause the smoke cloud to rise even under the most stable conditions, it may be anticipated that the cloud will lift entirely off the ground after a short distance of travel. If, however, a wind of considerable velocity is blowing, this lifting from the ground will not occur.

Although the heat produced in the smoke generator promotes a rise, it has little effect upon the spread of the smoke cloud. The spread that occurs is due to initial turbulence and this soon damps out. Consequently, if it is desired to produce continuous clouds of smoke from a series of individual generators, it is necessary to place the generators very close together; otherwise, the individual plumes may not merge for a long way downwind. This situation holds for smooth terrain. However, if the terrain is covered with shrubbery, for example, the lateral spread of the cloud is greatly increased as a result of the mechanical turbulence produced by the wind flowing through the shrubbery.

7-2.2.2.2 Unstable Conditions

When the air current is turbulent because of thermal instability, atmospheric diffusion takes place to such an extent that the initial, transient behavior of the cloud, due to the heat and turbulence from the generator, is of little significance. The aerosol cloud continues to rise and spread as it travels downwind until the cloud becomes so thin that its boundaries are no longer distinguishable to the eye. If a time exposure were to be taken of the cloud, it would appear as a cone with its apex at the generator and its axis rising at an angle from the horizontal, the angle of rise depending upon the degree of instability and the wind velocity. An instantaneous view of the cloud would show that it is furrowed and broken by variations in the wind direction and sudden upward convective currents.

The lower air is thermally unstable when the negative temperature decrease with altitude is more than 1°C per 100 meters of elevation near ground level. This negative gradient may continue indefinitely upward. Thus, in thunderstorms, cumulus clouds often rise to a height of several miles; a smoke cloud would be carried to the same height.

Under other circumstances, a current of warmer air may be blowing at an elevation of a few hundred feet so that the temperature gradient may become zero, or even positive, giving an inversion at this elevation. There is no tendency for the lower air to rise through this warmer lighter layer, and a definite ceiling will be established for the convective turbulence. Within this layer the atmosphere turns over and over, and the smoke may become diffused throughout the layer before it has traveled very far. However, eddy diffusion always occurs at the boundaries of the upward convective currents, causing some smoke to diffuse throughout the settling layer of cooler air even with a high convective ceiling.

The rate of rise of the convective current increases with thermal instability. The angle of rise of the smoke cloud (as a statistical average) is inversely proportional to the wind velocity. With zero wind, the convective currents rise directly upward. As the wind increases, the direction of the convective current is inclined increasingly away from the vertical.

7-2.2.2.3 Estimation of Atmospheric Diffusion[3]

Two expressions were derived which enable the concentration x (grams per cubic centimeter) at a given point in a smoke cloud to be predicted from knowledge of the rate of emission of particulate matter and of certain meteorological properties of the atmosphere. These equations for predicting the concentration from continuous point and line sources at ground level are:

Continuous point source emitting Q grams per second:

$$\chi_p(x,y,z) = \frac{2Q}{\pi C_y C_z \overline{U} x^{2-n}} \exp\left[-x^{n-2}\left(\frac{y^2}{C_y^2}+\frac{z^2}{C_z^2}\right)\right] \quad (7\text{-}4)$$

Continuous crosswind infinite line source emitting Q grams per second per centimeter:

$$\chi_L(x,z) = \frac{2Q}{\pi^{1/2} C_z \overline{U} x^{1-2n}} \exp\left[\frac{-z^2}{C_z^2 x^{2-n}}\right] \quad (7\text{-}5)$$

where the space coordinates x, y and z (origin at the source) refer to the downwind, crosswind, and vertical directions, respectively; $\overline{U}$ is the mean wind velocity; C_y and C_z are generalized eddy diffusion coefficients; and n is a parameter referring to the stability of the atmosphere, the numerical value of which varies between zero and unity These equations indicate that the concentration varies directly with the source strength Q and approximately inversely with the mean wind velocity $\overline{U}$. The distribution of concentration in the crosswind direction and in the vertical direction is approximately Gaussian; however, due to ground reflection, the vertical distribution corresponds to only one-half of the Gaussian curve. If the terrain is level and there is only a small temperature gradient, n is approximately 0.25. Under these conditions, the peak concentration downwind from a point source will decrease as $x^{-1.75}$, and for a line source as $x^{-0.88}$

7-2.3 SPECIFIC PROPERTIES OF MILITARY SMOKES

Smokes are used for four basic military purposes: (1) for screening, (2) for signaling, (3) for tracking and acquisition, and (4) for disseminating (see Paragraph 7-3) of agents in riot control and other applications. While smoke may be produced from a large number of chemicals in a variety of ways, only a few of these meet the specific requirements for a military smoke. The ideal military smoke material will:

a Be available in sufficient quantities for large-scale production of the mixture at a relatively low cost.

b. Be easily and efficiently disseminated without the use of elaborate equipment.

c. Be persistent when disseminated, i.e., it will not evaporate, fall out or coagulate rapidly.

d. Be effective at a low concentration of material.

e. Be substantially nontoxic; noncorrosive to equipment, and, except for control agents, nonirritating to the eyes, throat and skin.

f. Be suitable for large-scale manufacture, storage, and transportation, without hazard or deterioration.

7-2.3.1 Screening Smokes

Screening smokes are usually white and can be used to:

a. Conceal movements, intentions, equipment, and installations of friendly forces from ground observation.

b. Blanket friendly positions and installations in order to conceal them from air observation and attack.

c. Prevent aimed fire on approaching friendly aircraft, i.e., to screen the landing of airborne troops by parachute and glider.

d. Provide an extensive, thin haze for concealment of friendly areas without seriously impeding close-range vision.

e. Establish dummy screens to deceive observers.

f. Communicate.

g. Form a thermal radiation attenuation screen.

There are three types of smoke screens. A smoke screen laid over friendly areas to hinder enemy aerial observation and visual precision bombing is called a *blanket screen*. This type screen is formed by the gradual merging, downwind from the source of generation, of individual smoke streams. A *smoke haze* is normally established in a battle area to conceal friendly activities from observation and ground fire. It is formed in much the same manner as a blanket screen. Usually, however, a smoke haze is less uniformly dense than a smoke blanket. A *smoke curtain* is a dense, vertical development to conceal objects at ground level from observers at ground level.

Under many circumstances these distinctions disappear. For example, a smoke curtain may in-

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terfere with aerial observation or a blanket screen may settle to the ground and become a smoke curtain. These distinctions are important for defensive screening only, inasmuch as offensive use of smoke has the primary objective of blinding unfriendly forces by enveloping them in a dense blanket of smoke at ground level. Due to the required subsistence of smoke screens, large quantities of near optimum materials must be used. Of the large number of available smoke-producing chemicals, only a few have been found suitable for use in the production of military smoke screens.

7-2.3.2 Signal Smokes

It is a prerequisite that smokes used for signaling and communications be clearly distinguishable from other smokes (and other clouds) produced for different purposes. Thus, the use of white, gray, and blanket smokes for signaling is very limited and colored smokes are normally used for this purpose. In addition, the use of several different colors allows more information to be transmitted and also results in a clearer distinction between the smoke signals and a varying background. Effective methods for the production of colored smoke, including explosive dissemination, involve the vaporization and condensation of a dye; therefore, the dye must be heat-stable so that it can be rapidly vaporized at a relatively high temperature without appreciable thermal degradation. In addition to its color, important characteristics of a colored smoke include:

a. Visibility (the conditions under which the cloud can be seen and its color recognized).
b. Duration (the time period during which smoke is evolved from a munition).
c. Persistence (the total period of time during which a cloud is visible).
d. Volume (the quantity of smoke emitted; for colored smokes, volume has also been defined as the cross-sectional area of a cloud presented to an observer).

Although not as important as in the case of screening smoke, the smoke cloud should be as nontoxic, nonirritating, and noncorrosive as possible. Information on the composition, method of dissemination, measurement, etc., of colored smokes is contained in Paragraph 7-3.4.

7-2.3.3 Tracking and Acquistion Smokes

Smoke-producing devices such as generators or tracers are used as an aid in the optical tracking of projectiles, high speed aircraft, and missiles both at sea level and high altitudes. These devices optimize the ability to locate and track vehicles along the flight path and minimize the possibility of losing significant data. Requirements for optical tracking aids vary considerably because of the wide range of conditions encountered in the tracking of test vehicles operating over a wide range of altitudes and speeds. No single smoke agent or generating system will satisfy all requirements and numerous smoke-producing methods are necessary. Each is designed for a particular application, emphasizing certain ideal characteristics.

While the value of a screening smoke is due to its absorbing and light-scattering power, the visibility of a smoke tracking aid is due, chiefly, to its light-scattering power. The ideal tracking and acquisition smoke should have the following characteristics:

a. Be efficient on a weight and volume basis.
b. Have the ability to function and perform at altitudes where pressure is low, and water vapor and oxygen concentrations are small.
c. Have the ability to function through the range of temperatures encountered from ground temperature to the minimum high altitude temperature.
d. Require little power for generation and dispersion.
e. Be as nontoxic, nonexplosive, and noncorrosive as possible with regard to both smoke chemicals and products.

7-2.3.4 Smoke for Dissemination of Agents

Agent smokes for riot control and other purposes are produced in much the same way as colored signal smokes. In many cases, a vaporization process is followed by a condensation process in which the agent condenses to form the disperse phase of the smoke. Agent smokes may be disseminated by explosive means as well as by some

of the other methods discussed in Paragraph 7-3. The physiological effectiveness of materials disseminated in this way depends strongly on the particle size. While visibility of the smoke may or may not be important, the volume of smoke and its duration is important. It is also necessary that the vaporization and condensation process be efficient and produce a minimum of undesired changes in the agent being dispersed.

7-3 DISSEMINATION TECHNIQUES

Dissemination refers to the process by which a chemical agent is converted into a cloud consisting either of vapor or fine particles, suspended in the air. For agents such as smoke, which are disseminated as a particulate cloud, the process usually involves the formation of small particles of the dispersed phase and the distribution of these particles in the air.

7-3.1 FORMATION OF THE DISPERSED PHASE

The dispersed phase can be formed in two ways: (a) by condensation processes in which molecules of a vapor unite to form the particles of the dispersed phase, and (b) by dispersion processes in which the particles are formed by the breaking up of a solid or liquid material. In the first case, the specific surface (the total surface per unit-volume of the material) decreases; while in the second case, the specific surface increases.

7-3.1.1 Vapor Condensation Processes

The dispersed phase of most particulate clouds is produced by condensation from the vapor phase and involves the uniting of vapor molecules to form larger particles. The formation of a dispersed phase by this method involves two steps: (a) producing the vapor in a supersaturated state, and (b) condensing the supersaturated vapor. The supersaturated vapor is usually obtained by: (a) the cooling of a warm vapor, or (b) a chemical reaction which results in the formation of a supersaturated vapor. In either case, the excess vapor will condense to form the particles of the dispersed phase. The condensation of a supersaturated vapor is accompanied by the liberation of heat so that this process will continue, once initiated, until equilibrium is reached. The production of a supersaturated vapor and formation of a dispersed phase by condensation are complex processes and proceed essentially simultaneously. Consequently, little direct information has been obtained on the early stages of particle formation.

Condensation of a vapor is facilitated by the presence of foreign particles. Insoluble foreign particles can absorb a thin film of vapor on their surfaces and behave as liquid droplets of equal size. If the foreign particle is soluble in the condensed liquid, the vapor pressure of the liquid is decreased and, consequently, the supersaturation required for rapid condensation is reduced. Charged droplets, which are formed due to the presence of ions, tend to have a larger surface and, hence, a lower vapor pressure which result in condensation at a lower supersaturation. If condensation, in the absence of foreign particles, were to start from a single molecule, the theory indicates that a much higher supersaturation would be required than that observed experimentally. Therefore, it is postulated that small aggregates of molecules, of approximately the critical size, are continually produced by random fluctuation in the vapor. Molecular aggregates smaller than the critical size will disappear, while those larger than the critical size will continue to grow.

In many cases of military interest, the supersaturated vapor is produced by the evaporation of a substance, followed by the mixing with cooler air of the relatively warm vapors produced. Condensation then follows, resulting in the formation of the dispersed phase. The particles in a smoke produced as the result of combustion are also due to vapor condensation. In this case, due to the higher temperatures involved, it is impossible to analyze the process in detail. Chemical reactions, including several for producing smokes of military interest, often involve a component of the atmosphere (such as water vapor) as one of the reactants.

7-3.1.2 Dispersion Processes

The formation of a dispersed phase by dispersion methods involves the subdivision of a solid or liquid into fine particles. The actual mechanisms by which the fine particles are produced and dis-

persed in the suspending medium are intimately related and not always completely understood. In the case of a liquid, energy applied to it causes the liquid to assume an unstable configuration which then breaks up into small droplets. A solid substance may be disrupted and dispersed into fine particles by application of energy, or the solid can be preground to the desired size and then dispersed into the suspending medium.

In the atomization of liquids, the energy is expanded mainly in: (a) forming new surfaces, (b) overcoming viscous forces in changing the shape of the liquid, and (c) meeting losses due to inefficient application of the energy to the liquid. Devices commonly used to disperse liquids are of three main types.

One type employs a high velocity gas or air jet to break up a liquid emerging from a nozzle. Atomizers of this type produce a very wide range of droplet sizes which can be somewhat reduced by trapping the larger droplets within the atomizer. The degree of atomization obtained by this method is influenced by the following factors:

a. The relative velocity of the air past the droplets.
b. The physical properties of the liquid, including surface tension, viscosity, and density.
c. The relative quantity of air expressed as the ratio of volume of air to volume of liquid.

Within a limited range, the Nukiyama Tanasawa equation applies, even though it is dimensionally incorrect.[6]

$$d_o = \frac{585\sqrt{\sigma}}{v\sqrt{\rho}} + 597\left(\frac{\mu}{\sqrt{\sigma\rho}}\right)^{0.45}\left(\frac{1000Q_L}{Q_A}\right)^{1.5} \quad (7\text{-}6)$$

where d_o is the diameter in microns of a single drop with the same ratio of surface-to-volume as a representative sample of the atomized droplets; v is the velocity of the air in centimeters per second relative to that of the liquid; Q_L/Q_A is the volume-flow-rate of liquid to the volume-flow-rate of air; ρ is the density of the liquid in grams per cubic centimeter; μ is the velocity of the liquid in poises; and σ is the surface tension in dynes per centimeter. This equation is used in estimating the performance of particulate cloud generators such as the venturi nozzle type, where the smoke-producing material is atomized prior to evaporation.

There are two other important types of atomizers which are of somewhat lesser military importance. The first of these types is the centrifugal atomizer in which the liquid is fed onto the center of a rotating disc, cone, or top and centrifuged off the edge, producing droplets of relatively uniform size. In the second type, the hydraulic atomizer, liquid is forced through a nozzle and is broken up into droplets. In this latter case, the atomization depends more on the physical properties of the liquid and the conditions of ejection from the nozzle than on the interactions between the liquid and the surrounding gas.

Dusts can be formed by the disruption of solid material or by the dispersion of a material, finely preground to a desired size.

The forces required to disrupt the solid material may be applied rather slowly by milling, crushing, or grinding, or rapidly through explosion or impact. In either case, the applied forces cause disintegration by splitting or cracking along planes of weakness in the material. The result is the formation of small fragments and fine particles released from the freshly formed surfaces by cracking on a microscale as the material is torn apart.

7-3.1.3 Combined Processes

Since mist dispersion methods will not produce particles of the correct size, in many cases the dispersed phase for smokes of military interest is obtained by condensation from a vapor phase which is formed by evaporation of the smoke-producing agent. However, in order to facilitate the transfer of heat to and the removal of the vapor from the surface of the agent, it is often atomized before it is evaporated. Particulate clouds can be developed by the atomization of a solution containing a nonvolatile or slightly volatile solute in a volatile solvent. The solvent evaporates and leaves the solute which condenses to form the dispersed phase of a particulate cloud. The explosive dispersion of volatile materials, such as the dyes used for colored smoke, is also a combined process. The explosion mechanically disperses, vaporizes, and

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mixes the material with cooler air, resulting in the formation of a particulate cloud.

7-3.2 MILITARY PRODUCTION OF SMOKE

Pyrotechnic munitions for producing smoke, whether for screening, signaling, or other purposes, are usually one of the following general types:

a. Venturi Thermal Generator Type. The smoke-producing material and the pyrotechnic fuel block required to volatilize the smoke material are in separate compartments. The smoke-producing material is atomized and vaporized in the venturi nozzle by the hot gases formed by the burning of the fuel block.

b. Burning Type. Burning-type smoke compositions are intimate mixtures of chemicals. Smoke is produced from these mixtures by either of two methods. In the first method, a product of combustion forms the smoke or the product reacts with constituents of the atmosphere to form a smoke. In the second method, the heat of combustion of the pyrotechnic serves to volatilize a component of the mixture which then condenses to form the smoke.

c. Explosive Dissemination Type. The smoke-producing material is pulverized or atomized and then vaporized, or a preground solid is dispersed by the explosion of a bursting charge.

It is to be noted that smoke is also produced for military purposes by other than pyrotechnic means. For example, certain screening-smoke materials can be disseminated by mechanical smoke generators and others by the use of airplane spray tanks. Signals and tracking aids can be generated by using hot exhaust gases from aircraft or tank engines to vaporize the smoke-producing materials.

The ingredients used in smoke-producing chemicals and combustion products, and/or the condensed vapor particles produced in a smoke, should be considered to be irritating and/or toxic. Care should be exerted in working with smoke-producing materials and the resulting smokes, especially regarding the inhalation of high concentrations and long exposures thereto. When investigating new materials the proper references should be consulted[14,15,16,17] and if little or no information is available, extreme caution should be exerted.

The remaining sections of this chapter emphasize production of smoke by pyrotechnic means; however, the same principles are applicable to other methods for producing smoke, some of which are briefly discussed.

7-3.3 WHITE SMOKES

White smokes are widely used for screening, acquisition and tracking, fire control, and signaling purposes. They can be produced from many chemicals in a variety of ways and, in general, are more efficient on a weight basis than colored smokes.

Relatively few of the methods for producing white smoke are of value for production of the large amount of smoke required for screening purposes which is one of the important uses for white smoke. Because of the large amount of smoke required, it is important that the maximum effect be obtained per unit-weight of smoke-producing material. This will depend on: (a) the weight of the material available to form smoke particles, whether this was originally present in the mixture or is contributed from the atmosphere, and (b) the efficiency of conversion of the smoke-producing material into smoke particles having the optimum light-scattering and obscuring capability.

Formation of smoke particles by condensation from the vapor phase is the only practical way to produce the large amount of white smoke required for military screening purposes. The hot vapor is usually produced by volatilization or by chemical reactions in which one reactant is normally a component of the atmosphere. Examples of the three most widely used screening smokes are:

a. Oil smoke, which is produced by the volatilization and condensation of oil.

b. White phosphorus smoke, which is produced by chemical reaction with the atmosphere.

c. Zinc chloride smoke, which is produced by a combination of volatilization and chemical reaction.

Oil smokes are normally produced by venturi-type thermal generators, although intimate mixture burning types of munitions have been de-

veloped for dissemination of oil smoke. Zinc chloride smoke is produced by a burning-type munition. White phosphorus smoke for screening is normally produced by a bursting-type munition.

7-3.3.1 Oil Smoke

A very satisfactory white screening smoke can be produced by the vaporization and condensation of an oil that has a high boiling point and a low volatility. The first successful generator for producing oil smoke was the M1 mechanical smoke generator. In this generator the smoke oil was flash evaporated at a relatively high temperature, with water added to prevent coking. The equipment was heavy and complicated, including gasoline engines to operate the necessary pumps and blowers, coils for the evaporation of oil and water, and burners using fuel oil to heat the coils. In spite of their many disadvantages, these generators, along with similar types, were widely used during World War II.

7-3.3.1.1 Venturi Thermal Generators

Toward the end of World War II another smoke generator, the Hessien, was developed for the U. S. Navy in which the fog oil was atomized, mixed with the hot gases produced by the combustion of a fuel, and vaporized in a venturi throat. The development of venturi-type thermal-generator munitions using pyrotechnic fuel blocks was also accomplished during World War II; however, these items were not fully ready for production until after the War.

7-3.3.1.1.1 Operation of Venturi Thermal Generators

The operation of a venturi-type thermal generator to produce a smoke involves the atomization of the liquid, the vaporization of the droplets produced, and the dispersion of the vapor in a stream of hot gases. A typical unit, shown schematically in Figure 7-3, consists of:

a. a fuel block which, on burning, produces the hot gases,

b. a chamber containing the liquid to be vaporized and dispersed, and

c. a high velocity vaporizer tube in the form of a venturi.

A pressure tube connects the agent compartment and the fuel compartment and permits the pressure developed by the fuel block to aid in forcing oil through an orifice into the venturi throat. Here the oil is mixed with the hot gas stream flowing through the venturi. The high velocity of the gases promotes atomization of the incoming oil stream and the droplets are quickly vaporized. The rate of feeding is governed by the pressure differential between the agent compartment and the throat, the size of the feed orifice, and, to a minor extent, the resistance to the flow through the feed tube. Little decomposition of the agent is caused by the relatively high temperatures required for rapid evaporation due to the short period of exposure. The efficiency of this type of generator is highest when the agent is heated to a rather high temperature for the shortest possible time rather than a lower temperature for a longer period. The particle size of a smoke produced in a venturi thermal-generator type of munition can be defined in terms of: (a) the Nukiyama Tanasawa equation (Equation 7-6), modified to include the effect of system heat upon the aerosol, and (b) the thermodynamic properties of both the liquid and the pyrotechnic combustion products at the point of mixing, which controls the amount of liquid vaporized. Thus, the smoke formed can be considered to be made up of two parts: the larger particles produced predominantly by the atomization process, and smaller particles produced by vaporization and condensation.

The portion of the liquid vaporized depends on the heat transferred from the hot gases. The amount vaporized is significantly affected by mass flow rates, mean specific heat, and initial gas temperature. With proper design of the venturi, there is sufficient time for the heat to be transferred from the gases to the liquid. The overall process in the venturi can be considered to be essentially adiabatic.

Generators of this type regulate particle size through rapid dilution of the vapor with cool air. As mixing and cooling occurs, the saturated vapor condenses. For oil smokes, a very rapid coagulation occurs for a very short period of time causing the particles to grow. Dilution, however, occurs so rapidly that the coagulation is checked after a few

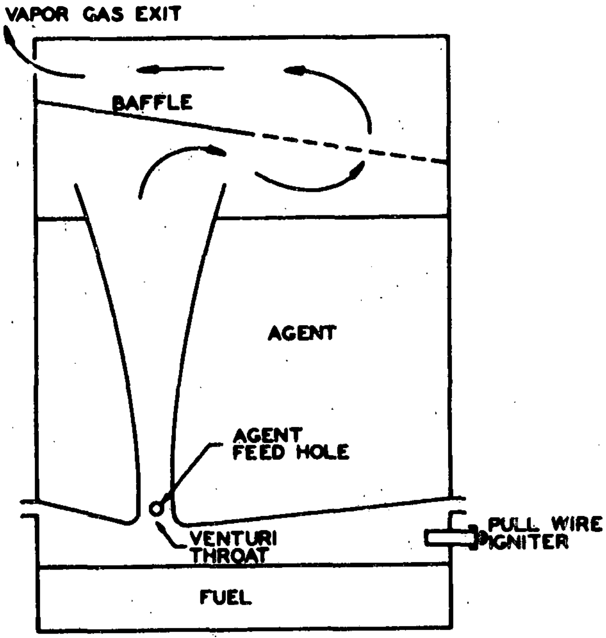

Figure 7-3. Typical Venturi Thermal Generator

thousandths of a second, and a remarkably narrow range of particle sizes results. If the generator is working well, it is possible to obtain a rough check on the particle-size range by a simple color test. If the sun's disc or any other bright light source, when almost obscured, appears red, the particle size is somewhat smaller than desired; if it appears magenta, the particle size is satisfactory; if it appears blue, the particle size is larger than desired for maximum screening effectiveness. If the smoke produced is not of a uniform particle size, the sun's disc will appear white and no conclusion can be drawn as to particle size being produced by the generators.

7-3.3.1.1.2 Fuel Blocks[4,18]

The heat and product gases produced by the burning of a pyrotechnic fuel block must:

a. Raise the temperature of the oil to the vaporization temperature.
b. Supply the latent heat of evaporation to the oil.
c. Supply the heat lost as sensible heat in the hot gases and hot container.
d. Supply the carrier gas to remove the oil vapor.

Ammonium nitrate-charcoal compositions have proved to be a satisfactory fuel block for the volatilization of fog oil.

The reaction between ammonium nitrate and carbon can be written:

$$NH_4NO_3 + C \longrightarrow CO + 2H_2O + N_2$$

if it is assumed that all the carbon is oxidized to carbon monoxide. If all the carbon is assumed to be oxidized to carbon dioxide the reaction is:

$$2NH_4NO_3 + C \longrightarrow CO_2 + 4H_2O + 2N_2$$

The volume of gas, measured at 0°C and 760 mm Hg, is about 0.97 liter per gram of mixture for the first reaction and 0.92 liter per gram for the second reaction.

Analysis of the gases produced by the burning of a typical ammonium nitrate fuel block (11 parts charcoal, 3 parts linseed oil, and 83 parts ammonium nitrate) gave the following:

H_2O	48.8%	CO_2	13.5%
NH_3	0.6%	CO	5.2%
N_2	26.1%	H_2	5.8%

which corresponds, approximately, to the reaction:

$$6NH_4NO_3 + 4C \longrightarrow 11H_2O + CO + 3CO_2 + 6N_2 + H_2$$

As illustrated in Chapter 3, this reaction should yield nearly one liter of gas, measured at 0°C and 760 mm Hg, per gram of mixture burned. Approximately 0.685 kcalories per gram of mixture is evolved when the mixture is burned.

Fuel blocks can be pressed using a binder, or they can be cast. In either case, the burning rate, which determines the heat and gas evolution rates, is roughly proportional to the area of the burning surface. For a fixed burning area, the rate of burning can be changed by:

a. Varying the size of the charcoal,
b. Modifying the surface of the charcoal, and/or
c. Changing the composition of the fuel block.

Carbon is normally the least-uniform ingredient and, therefore, causes most of the variation

TABLE 7-2
CHARACTERISTICS OF TYPICAL OIL SMOKE POTS

Characteristic	*Type Device*	
	Floating (Fig. 7-3)	*Training (Fig. 7-4)*
Size, in.	13 high by 13 dia.	5.7 high (including fuze) by 2.5 dia.
Venturi Orifice Diameter, in.	0.0890	0.076
Weight, lb	14.5 (oil) 12.0 (fuel)	0.24 (oil) 0.22 (fuel)
Oil Agent	SGF No. 1 or 2	SGF No. 1 or 2
Fuel Block Composition	*Fast-Burning Top Mixture* 86% NH_4NO_3 11% Charcoal 3% Linseed Oil *Slow-Burning Base Mixture* 82% NH_4NO_3 8% NH_4Cl 7% Charcoal 3% Linseed Oil	 82% NH_4NO_3 11% Charcoal 4% KNO_3 3% Linseed Oil
Ignition	Bouchon fuze (M208) "spits" through venturi igniting quickmatch & starter	Bouchon fuze (M201A1) (similar to floating type)
Burning Time, min	12 ± 1.5	1.2 ± 0.25
Application	Screening, used singly or in multiple on land or water	Grenade type, used for training purposes
Obscuring Power	- - -	Single pot fills a 13,000 cu ft room and totally obscures objects 4-6 feet away.

in burning for supposedly identical fuel blocks. Treatment of the carbon with chemicals (such as potassium carbonate or similar alkali chemicals) increases the burning rate while treatment with an acid will decrease the burning rate. The substitution of potassium nitrate, sodium nitrate, or ammonium chlorate for part of the ammonium nitrate will cause an increase in burning rate. A reasonable explanation for the increase is that these compounds form carbonates when burned with charcoal. On the other hand, adding ammonium chloride or substituting naphthalene (or starch in a cast fuel block) for charcoal will reduce the burning rate.

An increase in either the initial temperature or the pressure in the fuel block chamber will also increase the burning rate. Surging (a rapid burning with a high rate of gas evolution followed by slower burning with a low rate of gas evolution) is sometimes observed. This objectionable cyclic be-

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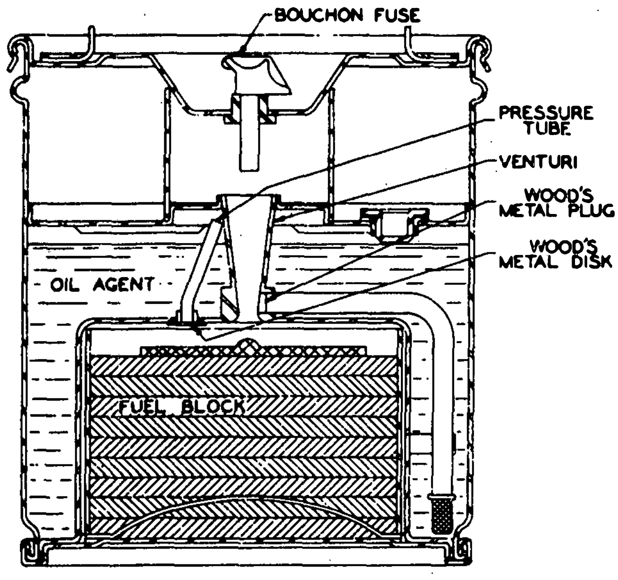

Figure 7-4. Typical Oil Smoke Pot (Floating)

havior is probably due to variations in the charcoal used inasmuch as surging is favored when a blend of slow- and fast-burning charcoal is used to make the fuel block.

Because charcoal may cause undesirable variations in the burning characteristics of a fuel block, attempts have been made to develop a fuel block which does not contain charcoal. A mixture of guanidine nitrate, ammonium nitrate, linseed oil, and ammounium dichromate was found to be only partially satisfactory. Reasonable success was obtained using polysulfide ammonium perchlorate as a binder and a substitute for all or part of the carbon in a castable fuel block. This reduced or eliminated the swelling and cracking observed in standard ammonium nitrate-carbon fuel blocks.

7-3.3.1.1.3 Typical Venturi Thermal Generators

Characteristics of typical venturi-type thermal generators are given in Table 7-2. Figures 7-4 and 7-5 illustrate schematically two types of oil fed smoke pots.

7-3.3.1.2 Other Methods for Producing Oil Smoke

Before the development of the M1 smoke generator, common methods for producing oil-based smoke screens included the reduction of air supply to the boilers of naval ships, the use of smudge

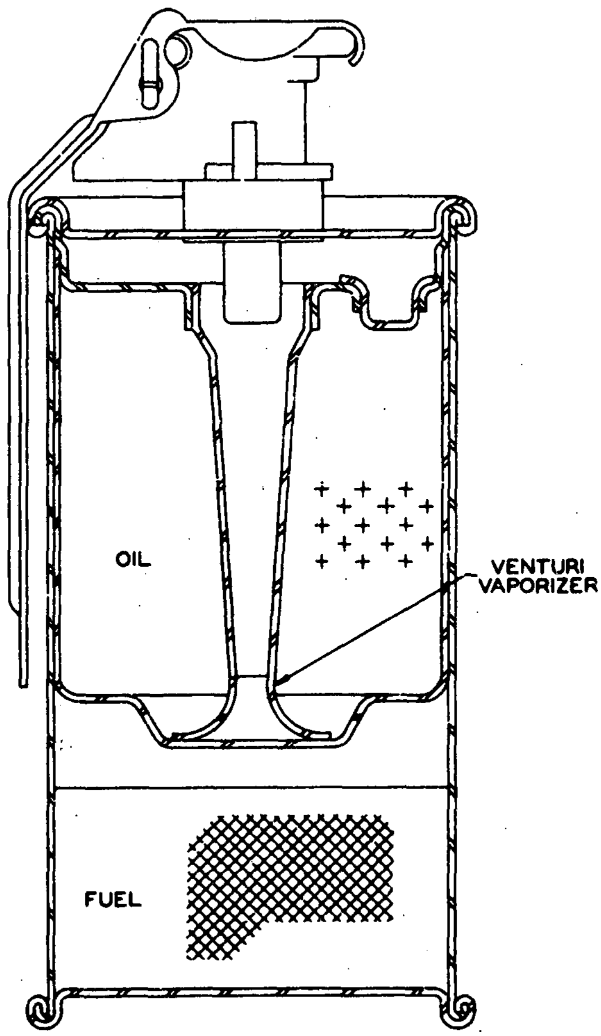

Figure 7-5. Typical Oil Smoke Pot (Training)

pots similar to those used in orange groves in the United States, and the Hasler generator developed and used by the British in the Battle of Britain. In all cases, the smoke produced was brownish-gray to black in color because the oil was partially decomposed thus yielding free carbon. In general, the smoke produced had poor screening properties and limited persistence.

Two oil smoke generator mixes which were reasonably satisfactory were developed during World War II. The first was a mixture of sawdust and charcoal impregnated with a solution of potassium chlorate and a high-boiling point oil (Diol) which had been jelled by the addition of

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a small percentage of soap. The other mixture consisted of jellied oil and black powder. In each case, the ideal mixture was one in which all of the fuel but none of the oil was oxidized, and in which the amount of heat produced was sufficient to vaporize all of the oil. The smoke exit orifice was important in controlling the flaming tendency of the mixture, the particle size of the smoke produced, and the pressure within the smoke pot.

Considerable effort was directed toward the development of smoke generators, using the sensible heat in exhaust gases from vehicle and aircraft engines for the evaporation of oil to form screening smoke. Results indicated that the amount of smoke produced was not adequate for screening purposes but was adequate for signaling. In an attempt to increase the amount of smoke produced, the exhaust gases were burned in an afterburner, thereby increasing their temperatures and heat content. With this modification, satisfactory smoke screens were produced by aircraft using internal combustion engines.

7-3.3.2 Phosphorus Smokes

White smoke consisting of small droplets of phosphoric acid have been widely used for military purposes. These droplets result from the reaction of phosphorus pentoxide, formed by the burning of phosphorus or phosphorus-containing compounds in the air, and the water vapor in the air, or:

$$P_4 + 5O_2 \longrightarrow 2P_2O_5$$
$$P_2O_5 + 3H_2O \longrightarrow 2H_3PO_4$$
$$H_3PO_4 + nH_2O \longrightarrow H_3PO_4 \text{ (dilute)}$$

The concentration of phosphoric acid in the droplets is determined by the relative humidity. Methods which have been used to form phosphorus pentoxide for military smokes utilizing phosphorus include:

a. burning in air of white phosphorus (which is spontaneously flammable),

b. burning in air of the phosphorus vapor (produced by the evaporation of red phosphorus in a fuel-oxidant mixture), and

c. burning in air of phosphine (produced by the action of a metal phosphide with water).

Phosphorus vapor is extremely toxic and causes bone decay; however, it is not present after the smoke is formed. Phosphorus pentoxide and phosphoric acid are not toxic in small concentrations, although they may be irritating to the eyes, respiratory tract, and skin. Phosphorus smokes have relatively little effect on metals.

7-3.3.2.1 White Phosphorus

White phosphorus is widely used in bursting-type munitions to produce smoke screens for ground-combat operations, and for signaling and spotting purposes. Slow-burning fragments of white phosphorus, produced and spread by an explosive burster, are incendiary while burning. Since burning white phosphorus produces flesh burns which are slow to heal, it is an excellent harassing agent.

White phosphorus is the most efficient smoke producer on a weight basis; however, the screening effectiveness of white phosphorus in bursting-type munitions is slight. Most of the charge burns within seconds following the burst, resulting in a smoke concentration many times that required for effective screening. In addition, the temperature rise in the cloud immediately surrounding the burst is sufficient to produce a strong thermal updraft which rapidly lifts the cloud from the ground so that the smoke cloud pillars. This may be helpful for signaling purposes but generally reduces the effectiveness of white phosphorus as a screening smoke.

Two general ways to improve smoke-producing efficiency are possible. The first involves reduction of the heat of combustion, which can be accomplished only by using different phosphorus compounds. The second method, which is more attractive, involves controlling the rate of combustion by reducing the fragmentation of the phosphorus. Several methods for controlling the fragmentation of phosphorus have been tried, including the addition of mechanical reinforcement such as steel wool,[19] asbestos, plastic tubes, wire screens, and other devices, causing ejection of the phosphorus in pieces of predetermined size. Other methods attempted involve the alteration of the physical properties of phosphorus so as to produce a plastic mass with low shattering characteristics.

Plasticized white phosphorus,[20] PWP, was found to be the most promising development for

Figure 7-6. Typical WP-Filled Device (M15 WP Smoke Hand Grenade)

control of the fragmentation of phosphorus and pillaring of the smoke. This consists of an intimate mixture of granulated white phosphorus in a viscous rubber solution. The material burns more slowly and the particles do not disintegrate by melting. As a result, pillaring is reduced and the effective screening time is greatly prolonged. Test results have indicated that plasticized white phosphorus produces distinctly better smoke screens than similar phosphorus-filled rounds. The antipersonnel incendiary action of PWP is as good as that of WP.

7-3.3.2.2 Burning-Type Mixtures Containing Red Phosphorus

Red phosphorus, the comparatively inert allotropic form of phosphorus, is used in burning-type munitions mainly for signaling purposes. Compositions consisting of red phosphorus and certain oxidants or fuels are relatively slow-burning and are sometimes used in sea markers. The chemical reactions may be quite involved. For example, the main reaction for a burning mixture of calcium sulfate and red phosphorus appears to be:

$$30CaSO_4 + 19P_4 \longrightarrow 6Ca(PO_3)_2 + 12Ca_2P_2O_7 + 10P_4S_3$$

The heat produced by this reaction vaporizes the remaining red phosphorus contained in the smoke mixture. The phosphorus vapor burns on contact with air. Some sulphur dioxide is formed when the P_4S_3, produced in the above reaction, burns along with the phosphorus vapor:

$$P_4S_3 + 8O_2 \longrightarrow 3SO_2 + 2P_2O_5$$

In the presence of moisture, there is a tendency for red phosphorus to slowly oxidize due to the presence of small quantities of copper and iron. This may result in ignition difficulty and an overall decreased performance of the smoke item. Stable red phosphorus has been produced by decreasing or eliminating these impurities.[21,22,23]

7-3.3.2.3 Metal Phosphides

Metal phosphides, especially calcium phosphide, which was first produced commercially in 1920, have been used in sea markers. In these markers the metal phosphide reacts with water to form phosphine, which then burns in air to produce phosphorus pentoxide and water. For calcium phosphide:

$$Ca_3P_2 + 6H_2O \longrightarrow 3Ca(OH)_2 + 2PH_3$$
$$2PH_3 + 4O_2 \longrightarrow P_2O_5 + 3H_2O$$

The rate of reaction is governed by the access of the water and by the back pressure of the gas produced. Calcium phosphide has been the most satisfactory for this purpose. Aluminum phosphide is difficult to react and is slow-burning, whereas magnesium phosphide reacts too rapidly.

7-3.3.2.4 Other Reactions for Producing Smokes Containing Phosphorus

Other methods for producing phosphorus-containing smokes include:

a. The dispersion of phosphorus in a solvent such as carbon tetrachloride or carbon disulfide. The solvent evaporates and the finely divided phosphorus burns in the available oxygen and produces a dense white smoke.

b. The reaction of phosphorus trichloride with bases such as ammonia and amines. The

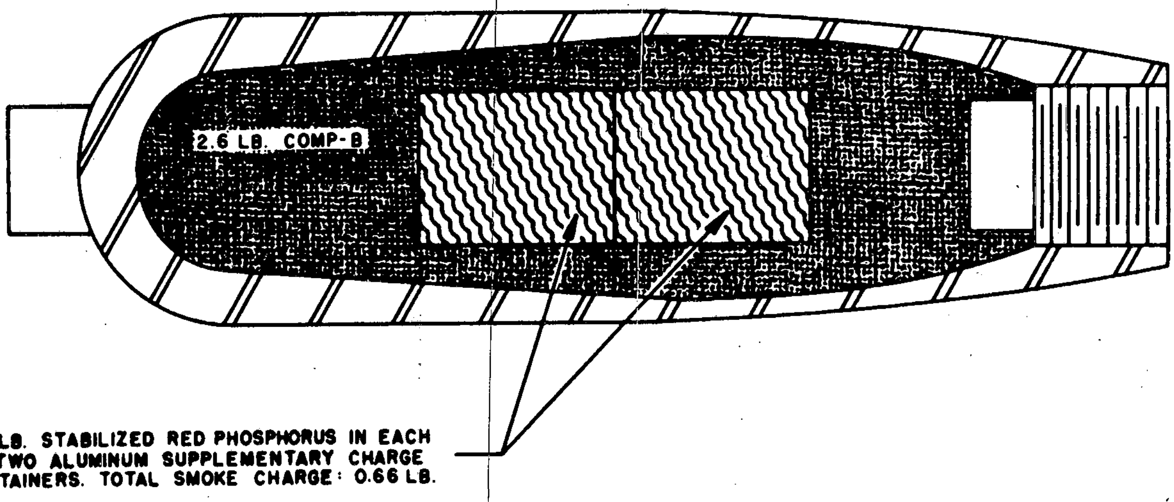


Figure 7-7. Typical Red Phosphorus-Filled Device

reactions are complex as illustrated in the following example:

$$PCl_3 + NH_3 \longrightarrow PCl_2NH_2 + HCl$$
$$PCl_2\ NH_2 + NH_3 \longrightarrow PCl(NH_2)_2 + HCl$$
$$PCl(NH_2)_2 + NH_3 \longrightarrow P(NH_2)_3 + HCl$$
$$HCl + NH_3 \longrightarrow NH_4Cl$$

The smoke is composed of a mixture of aminophosphorus chlorides and NH_4Cl; the smoke produced is considered irritating but not toxic; phosphorus trichloride is not excessively corrosive to any metal affected by hydrochloric acid; either wet or dry it is quite corrosive to flesh.

c. The dispersion of phosphorus sulfides in carbon bisulfide. The solvent evaporates and the finely divided particles of phosphorus sulfide burn readily in air; total combustion of these sulfides yields phosphorus pentoxide and sulphur dioxide:

$$P_4S_3 + 8O_2 \longrightarrow 2P_2O_5 + 3SO_2$$
$$2P_2S_5 + 15O_2 \longrightarrow 2P_2O_5 + 10SO_2$$

Both products react with water to produce sulfurous acid and phosphoric acid; the sulfides of phosphorus are harmless to both metals and flesh. The smoke produced is also relatively harmless to metals and personnel under normal conditions; however, prolonged exposure to high concentrations should be avoided.

7-3.3.2.5 Typical Devices

The characteristics of typical smoke-producing devices containing phosphorus are summarized in Table 7-3. Illustrations of such devices are shown in Figures 7-6 and 7-7.

7-3.3.3 Metal Chloride Smokes

A large number of metal chlorides have been used to produce white smoke. All of the metal chlorides react with water to varying degrees and this characteristic determines, to a large extent, their efficiency as smoke agents. While the methods by which they are disseminated depend on the particular metal chloride, once disseminated the metal chloride reacts with the water vapor in air resulting in the formation of hydrated oxides, or hydroxides and hydrochloric acid.

7-3.3.3.1 Liquid Metal Chlorides

The liquid metal chlorides can be disseminated by thermal vaporization followed by condensation, or by atomization. FM, a commercial form of titanium tetrachloride, has probably been the most widely used liquid metal chloride smoke agent.

7-3.3.3.1.1 FM Smokes

FM smoke agent, $TiCl_4$, is extremely reactive resulting in the formation of hydrated oxides, or with atmospheric moisture and, when used for screening, is often disseminated from aircraft

TABLE 7-3
CHARACTERISTICS OF TYPICAL DEVICES USING PHOSPHORUS FILLING

Characteristic	*Device*	
	WP Smoke Hand Grenade (M15)	*Projectile (T91 HE Water Marker)*
Size, in.	4½ high 2⅜ dia.	12¾ long 1¾ dia.
Charge Weight	15 oz PWP	2.6 lb Comp B. 0.66 lb Stabilized Red Phosphorus
Ignition	M206A1 fuze HE burster	M500A1 fuze Comp. B
Screening Capability	Scatters WP over a 20 yd radius	Explodes on impact—50 ft high; 50 ft dia; cloud duration 3 min—25 mph wind
Application	Thrown, bursting charge explodes, 4-5 sec delay.	Used in 90 mm munition (white marker)

spray tanks.[24] Its reaction with water vapor is relatively complex. First, the titanium tetrachloride is hydrated. This reaction is followed by further hydrolysis yielding, finally, titanium hydroxide and hydrochloric acid. The smoke consists of a mixture of fine particles of solid titanium hydroxide, $Ti(OH)_4$; the hydrated oxide, $TiO_2 \cdot H_2O$; intermediate hydroxychlorides of titanium; and dilute HCl droplets. The sequence of reaction is:

$$TiCl_4 + 5H_2O \longrightarrow TiCl_4 \cdot 5H_2O$$
$$TiCl_4 \cdot 5H_2O \longrightarrow TiCl_3(OH) \cdot 4H_2O + HCl$$
$$TiCl_3(OH) \cdot 4H_2O \longrightarrow TiCl_2(OH)_2 \cdot 3H_2O + HCl$$
$$TiCl_2(OH)_2 \cdot 3H_2O \longrightarrow Ti(OH)_4 \cdot H_2O + 2HCl$$

Liquid FM is excessively corrosive to metal if moisture is present. With moisture, FM forms a solid, gummy deposit that clogs equipment. A 0.2 percent phosphorus solution in CS_2 and CCl_4, added to the FM, alleviates this problem.

Titanium tetrachloride can also be disseminated when dissolved in dichloroethane and similar materials. The solvent evaporates and the titanium tetrachloride reacts with the water vapor in the air to produce smoke.

7-3.3.3.1.2 Silicon Tetrachloride

Silicon tetrachloride is another liquid metal chloride which has been used to produce smoke. Silicon tetrachloride is, however, less reactive than titanium tetrachloride and, unless considerable moisture is present, little smoke is produced. The smoke particles produced from the reaction of silicon tetrachloride with water vapor are dilute hydrochloride acid droplets and hydrated silicon oxide. The reaction between silicon tetrachloride and water vapor is similar to that for titanium tetrachloride.

Silicon tetrachloride is less corrosive to metals than titanium tetrachloride. If dry, it can be stored in aluminum or steel containers. With moisture, silicon tetrachloride forms a gummy deposit which clogs equipment. Flesh burns from

silicon tetrachloride are similar to hydrochloric acid burns.

7-3.3.3.1.3 Stannic Chloride

Stannic chloride will produce a good smoke from relatively small amounts of material. The reactions of stannic chloride with water vapor are similar to those of titanium tetrachloride. The smoke is composed of HCl droplets and a mixture of four stannic hydroxy chlorides. In the presence of moisture they are nearly as corrosive as titanium tetrachloride. A gummy deposit on metals is formed by stannic chloride when moisture is present. The smoke is corrosive to anything affected by hydrochloric acid. Stannic chloride produces burns similar to strong acid burns.

7-3.3.3.2 Solid Metal Chlorides

Solid metal chlorides are normally disseminated by thermal vaporization followed by condensation. In most cases, the energy required to vaporize these agents is provided by a pyrotechnic heat source. The hydrolyses reactions for the metal chlorides which have been used as smoke agents are:

$$CuCl_2 + 2H_2O \longrightarrow Cu(OH)_2 + 2HCl$$
$$FeCl_2 + 2H_2O \longrightarrow Fe(OH)_2 + 2HCl$$
$$FeCl_3 + 3H_2O \longrightarrow Fe(OH)_3 + 3HCl$$
$$AlCl_3 + 3H_2O \longrightarrow Al(OH)_3 + 3HCl$$
$$ZnCl_2 + 2H_2O \longrightarrow Zn(OH)_2 + 2HCl$$
$$CdCl_2 + 2H_2O \longrightarrow Cd(OH)_2 + 2HCl$$
$$HgCl_2 + 2H_2O \longrightarrow HgO \cdot H_2O + 2HCl$$
$$SnCl_2 + 2H_2O \longrightarrow Sn(OH)_2 + 2HCl$$

7-3.3.3.2.1 HC Smokes

Zinc chloride is one of the most reactive of the solid metal chlorides used as a smoke agent. Although toxic, zinc chloride produced as the result of a pyrotechnic reaction is widely used for screening and signaling purposes.[15] Inasmuch as hydrochloric acid is produced by the reaction between zinc chloride and water vapor in air, the smoke is irritating to personnel and will react with any materials affected by hydrochloric acid.

The French, during World War I, were the first to produce a smoke mixture of this type. The mixture known as the Berger mixture consisted of zinc, carbon tetrachloride, zinc oxide, and kieselguhr. The last two ingredients served to absorb the carbon tetrachloride and to slow down the rate of reaction. As the smoke produced contained some carbon in addition to the zinc chloride, it was somewhat gray in color. An American improvement, the addition of an oxidizing agent, resulted in a whiter smoke. Other changes were made leading to the development of the smoke mixture, available at the start of World War II, known in the United States as HC. This mixture contained hexachloroethane as the chlorinating agent, zinc as the fuel, a perchlorate as an oxidizing agent, and ammonium chloride as a retarder. The British had a similar mixture containing hexachloroethane, zinc oxide, and calcium silicide as a reducing agent. Since neither of these mixtures was completely satisfactory early in World War II, the British mixture was modified by replacing the reducing agent, calcium silicide, with aluminum.

7-3.3.3.2.2 Chemistry of HC Smoke Mixtures[25,26]

The basic reaction between a completely chlorinated carbon compound and metallic zinc can be represented by the reaction:

$$C_xCl_y + y/2Zn \longrightarrow xC + y/2ZnCl_2$$

This reaction is highly exothermic with the evolution of 165.3 kilogram-calories or 581 gram-calories per gram of mixture if carbon tetrachloride is used, and 244.6 kilogram-calories or 565 gram-calories per gram of mixture if hexachloroethane is used as the chlorinating agent. If zinc oxide is added, the mixture will burn more slowly. The smoke produced is whiter due to the reaction between zinc oxide and carbon:

$$ZnO + C \longrightarrow CO + Zn$$

which removes the carbon from the smoke. The zinc produced by this reaction then reacts with additional amounts of the chlorinating agent. As the reaction between zinc oxide and carbon is endothermic, early attempts to use zinc oxide in HC-type smokes were only partially successful since the temperature reached was not high enough to cause complete reduction of the zinc oxide.

As the result of modifications made during the early part of World War II, HC smoke mixtures —as normally compounded for screening purposes

—now consist of approximately equal amounts by weight of zinc oxide and a chlorinating agent such as hexachloroethane or carbon tetrachloride, and a few percent of aluminum. The reaction might proceed through the following steps, when hexachloroethane is the chlorinating agent:

$$2Al + C_2Cl_6 \longrightarrow 2AlCl_3 + 2C$$

This reaction is exothermic, liberating around 280 kilogram-calories of energy. The aluminum chloride formed then reacts with the zinc oxide:

$$2AlCl_3 + 3ZnO \longrightarrow 3ZnCl_2 + Al_2O_3$$

This reaction is also exothermic, liberating 103.0 kilogram-calories. The overall reaction obtained by combining the above reactions is:

$$2Al + C_2Cl_6 + 3ZnO \longrightarrow 3ZnCl_2 + Al_2O_3 + 2C$$

This reaction is highly exothermic, liberating 383.5 kilogram-calories or 717 gram-calories per gram of smoke mixture. A second reaction sequence leading to the same overall reaction is possible. This sequence, which to some investigators better represents the actual course of the reaction, is

$$2Al + 3ZnO \longrightarrow 3Zn + Al_2O_3$$
$$3Zn + C_2Cl_6 \longrightarrow 3ZnCl_2 + 2C$$

Both of these reactions are exothermic, the first to the extent of 136.6 kilogram-calories, and the second to the extent of 219.8 kilogram-calories. The overall reaction with aluminum is similar to the reaction:

$$3CaSi_2 + 15ZnO + 5C_2Cl_6 \longrightarrow 15ZnCl_2 + 3CaO + 6SiO_2 + 10C$$

for the earlier smoke mixture containing calcium silicide as the reducing agent.

The extent of the reaction between zinc oxide and carbon can be varied by changing the proportion of aluminum in the smoke mixture. If the aluminum content in the smoke mixture is reduced, while the proportions of hexachloroethane and zinc oxide are kept constant, the amount of free carbon in the smoke is reduced. This results in a whiter smoke and also reduces the burning rate. The overall reaction where no carbon is produced is:

$$2Al + 9ZnO + 3C_2Cl_6 \longrightarrow Al_2O_3 + 9ZnCl_2 + 6CO$$

The amount of aluminum in the foregoing reaction can vary from 3.6 to 10.1 percent by weight. With the lower aluminum content, only carbon monoxide is formed; and, as the aluminum content is increased, free carbon begins to appear along with the carbon monoxide until at the upper limit all the carbon is in the form of smoke. If less than 3.6 percent of aluminum is used, both carbon dioxide and carbon monoxide are produced; and, as the percentage of aluminum is still further reduced, the ratio of carbon dioxide to carbon monoxide increases. The heat evolved varies from 356 gram-calories per gram of a smoke mixture containing 3.6 percent of aluminum to 717 gram-calories per gram of mixture containing 10.1 percent aluminum content. If carbon tetrachloride is used (Type-E HC mixture) instead of the hexachloroethane, the amount of aluminum for similar reactions to take place ranges from 5.37 percent to 10.2 percent. The variation in burning time with aluminum content, for mixture containing hexachloroethane (Type-C HC mixture), is illustrated by the data presented in Table 7-4.

TABLE 7-4
VARIATION OF BURNING TIME OF TYPE-C HC SMOKE MIXTURE WITH ALUMINUM CONTENT

(AN-M8, HC SMOKE GRENADE)

Aluminum Content, %	*Burning Time,* *sec*
9.0	55
8.4	64
8.0	65
7.5	71
7.0	84
6.5	96
6.0	107
5.5	147
5.5	200

The character of the zinc oxide also has an influence on the burning rate of the smoke mixture. HC smoke grenades which were loaded with a smoke mixture containing 6.25 percent aluminum, 46.9 percent hexachloroethane, and 46.9 percent

zinc oxide were found to have a wide range of burning times depending on the moisture, carbonate and sulfate content, and the particle size of the zinc oxide used. Very fine and very coarse zinc oxides form slower-burning mixtures than those of intermediate size. Fast-burning smoke mixtures result when moderately large-sized particles of zinc oxide with a low moisture and carbonate content are used, while slow-burning mixtures are produced when very small-sized particles of zinc oxide, or those having a high carbonate content, are used. A blend of a coarse and a fine zinc oxide results in a faster-burning mixture than would be predicted from the burning time of the individual oxides.

The apparent density of the zinc oxide has no direct effect on the burning time of the Type-C HC smoke mixture containing zinc oxide. For Type-E HC smoke mixtures, the consistency of the filling varies from wet-and-doughlike to dry-and-powdery as the relative density of the zinc oxide decreases. The rate of burning of the mixture also decreases as the relative density of the zinc oxide decreases.

If the aluminum content is reduced below five percent, the burning time becomes erratic. As a result, other means must be employed to further retard the burning rate. The substitution of basic zinc carbonate for zinc oxide, in a quantity not exceeding seven percent of the zinc oxide, is one method. The stoichiometric ratio of zinc to hexachloroethane, however, must be maintained. Other retarders which lengthen the burning time of the HC smoke mixture include urea and Monostral blue dye. Naphthalene was found to have a retarding action on the fast-burning mixtures but no definite effect on the slow-burning mixtures. Sucrose, Vinsol resin, and anthracene were tried but were not satisfactory.

HC smoke mixtures are relatively stable except when there are soluble chlorides in the zinc oxide or when water contacts the hexachloroethane. Although the sequence of events when water gains access to an HC smoke mixture containing hexachloroethane has not been established conclusively, it is reported[27] that in the presence of zinc dust and moisture C_2Cl_6 is reduced and tetrachloroethylene is one of the reaction products. Zinc dust is oxidized to zinc oxide and zinc chloride. Impurities such as chlorides, sulfates and nitrates accelerate the reaction.

7-3.3.3.3 Modified HC Smokes[28]

When a shortage of chlorine appeared imminent during World War II, attention was focused on the possibility of developing inorganic chlorine carriers derived from hydrochloric acid. It was found that anhydrous ferric chloride could be used in place of hexachloroethane in zinc chloride smoke mixtures. The following reactions involving aluminum, ferric chloride, and zinc oxide are thought to occur at high temperatures:

$$2Al + 6FeCl_3 + 9ZnO \longrightarrow Al_2O_3 + 6FeO + 9ZnCl_2$$

$$2Al + 2FeCl_3 + 3ZnO \longrightarrow Al_2O_3 + 2Fe + 3ZnCl_2$$

The heats of reaction per gram of smoke mixture for the above reactions are 186 and 378 gram-calories, respectively. Because of the hygroscopic nature of ferric chloride, compositions containing this ingredient are difficult to prepare in moist atmospheres. To obviate this difficulty, the use of ferric chloride complexes such as $KFeCl_4$ has been proposed.

In recent work,[29] hexachlorobenzene and Dechlorane (perchloropentacyclodecane, $C_{10}Cl_{12}$) have been used instead of the more volatile hexachloroethane. The smoke volume and burning time are comparable to the normal HC compositions; its stability during storage is better. No significant difference in relative toxicity was found; both smokes are toxic and produce degeneration of tissues in the respiratory system on long exposure.

Plastic bonding agents[30] were also successfully tried allowing the smoke compositions to be loaded into unusual-shaped containers. The filling and blending operations have been improved with improvement in uniformity of the mixtures. Storage characteristics of plastic bonded white smoke munitions were also better, although corrosion has not been completely eliminated.

7-3.3.3.4 Zinc Hexachlorobenzene-Potassium Perchlorate System

Zinc hexachlorobenzene-potassium perchlorate systems have been used in some cases for signaling

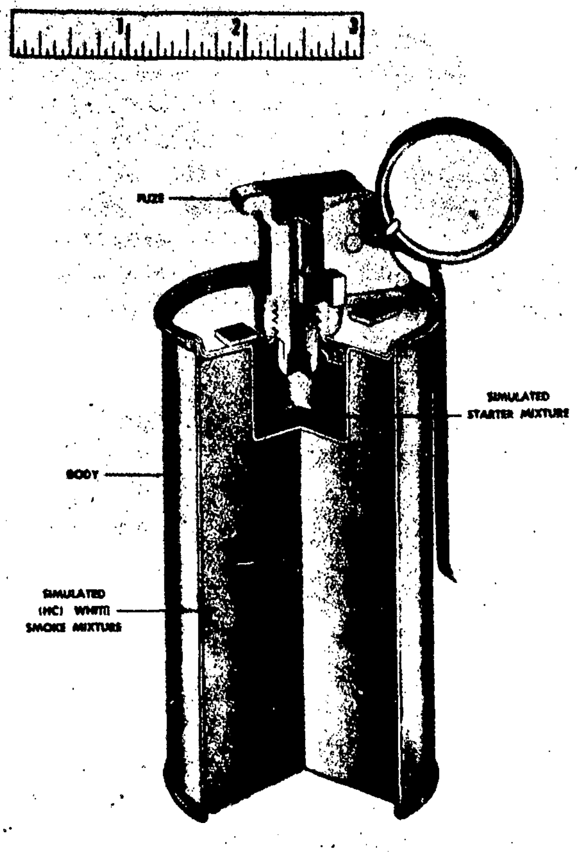


Figure 7-8. AN-M8 HC Smoke Hand Grenade

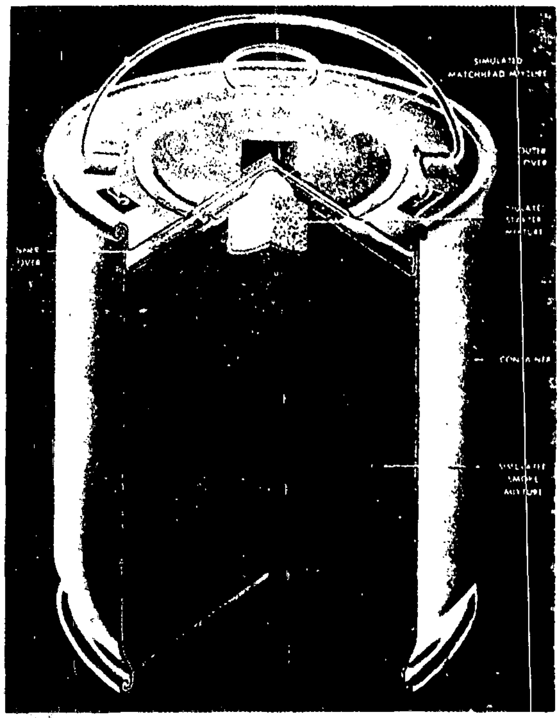


Figure 7-9. M5 HC Floating Smoke Pot

and marking purposes. Heat of combustion and differential thermal analysis have indicated that three chemical reactions are basically responsible for the preignition, ignition, and combustion phases of this ternary system.[31] These reactions are:

1. $3Zn + C_6Cl_6 \longrightarrow 3ZnCl_2 + 6C$
2. $4C + KClO_4 \longrightarrow KCl + 4CO$ (and CO_2)
3. $4Zn + KClO_4 \longrightarrow KCl + 4ZnO$

The agreement between the measured and calculated heats of combustion based on these reactions is good.

The first of these reactions is a relatively slow, exothermal reaction which takes place at, and above, the boiling point of hexachlorobenzene to produce carbon. Carbon, which is produced at a temperature above the transition point of potassium perchlorate, reacts with the latter at the boiling point of hexachlorobenzene, according to reaction 2. The latter reaction, together with reaction 1 to a limited extent, raises the system to a temperature above 500°C. At temperatures above the melting point of zinc (419°C), the preignition reaction 3 becomes highly exothermal and propagation ensues in the range of 520°C. Therefore, the production of carbon by reaction 1 is an important factor in the sensitivity of this composition to thermal ignition.

7-3.3.3.5 Typical Devices

Typical devices using HC type smoke mixtures are shown in Figures 7-8 and 7-9. Details and specifications for these devices are contained in Table 7-5.

7-3.3.4 Sulfuric Acid Smokes

Several white smokes are made up, at least in part, of droplets of dilute sulfuric acid result-

TABLE 7-5
CHARACTERISTICS OF TYPICAL DEVICES USING HC MIXTURE

Characteristic	*Device*	
	HC Smoke Hand Grenade (AN-M8)	*HC Floating Smoke Pot (M4A2)*
Size, in.	5.7 high 2.5 dia Four smoke emission holes in top	13 high 12 dia Three vent holes in top
Charge Weight	19 oz Type-C HC Mixture	23.5 to 27.5 lb HC Mixture
Ignition	M201A1 fuze plus ignition mix and starter mix	M207A1 fuze plus first fire charge and delay charge
Burning Time	105-150 sec	10-15 min
Application	Thrown, 1.2-2 sec delay—may be launched from rifle or carbine for screening or marking.	Screening

ing from the reaction of the smoke-producing chemical with water vapor in the air. In a number of cases, because of the presence of chlorine atoms in the original compound or mixture, dilute hydrochloric acid droplets are also produced. In this category, the FS smoke mixture of chlorosulfonic acid and sulfur trioxide, which is used for screening, is probably the most important. Prolonged exposure to this type smoke can be injurious and should be avoided.

7-3.3.4.1 Sufide Trioxide

This agent is usually dispersed into the atmosphere in fine particles either by mechanical atomization or thermal vaporization. The dispersed sulfur trioxide combines with water vapor in the atmosphere, resulting in the formation of tiny droplets of sulfuric acid:

$$SO_3 + H_2O \longrightarrow H_2SO_4$$

The acid then takes on more water vapor to produce particles of diluted acid which constitute the smoke cloud. Dry sulfur trioxide does not attack metals at ordinary temperatures. At red heat, sulfur trioxide vapors reacting with metals form metal sulfides and oxides. When the liquid comes in contact with the skin, sulfur trioxide causes burns that heal slowly. If water is present, sulfuric acid is formed which is corrosive to metals. As has been indicated, the smoke formed is corrosive to anything affected by sulfuric acid.

7-3.3.4.2 Oleum

Oleum is a solution of sulfur trioxide in sulfuric acid. The agent is dispersed in the same manner as sulfur trioxide. The sulfur trioxide reacts with water vapor in the air; the sulfuric acid thus formed and the sulfuric acid solvent absorb water to give smoke droplets of dilute sulfuric acid.

7-3.3.4.3 Chlorosulfonic Acid

This acid reacts with water similar to SO_3. Smoke is produced by dispersion of the acid into the atmosphere by mechanical atomization or thermal vaporization. When the dispersed acid mingles with water vapor, sulfuric acid and hydrochloric acid are produced:

$$HClSO_3 + H_2O \longrightarrow H_2SO_4 + HCl$$

Both acid products take on further water to give droplets of dilute sulfuric and dilute hydrochloric acid. The smoke produced, therefore, is corrosive to anything affected by sulfuric acid or hydrochloric acid and is irritating to the respiratory system, eyes, and skin of exposed personnel.

7-3.3.4.4 Sulfuryl Chloride

Sulfuryl chloride is dispersed in the same manner as sulfur trioxide by mechanical atomization or thermal vaporization. It reacts with water vapor from the atmosphere to give a smoke composed of dilute sulfuric acid and dilute hydrochloric acid droplets. In the presence of moisture, sulfuryl chloride is as corrosive to metal and flesh as is sulfuric acid. Dry sulfuryl chloride is corrosive to those materials affected by sulfuric or hydrochloric acid and will cause burns to the flesh similar to those of sulfuric acid.

7-3.3.4.5 FS Smoke

FS smoke agent consists of a mixture of 45 percent chlorosulfonic acid and 55 percent sulfur trioxide, and is slightly more reactive with water than FM smoke agent (Paragraph 7-3.3.3.1.1). The material can be dispersed by mechanical atomization or thermal vaporization. For producing smoke screens, it is often disseminated from spray tanks carried by aircraft. As the smoke consists of droplets of dilute sulfuric and hydrochloric acid, the smoke is corrosive to anything affected by these compounds. The smoke is very irritating to the nose and lungs and exposure should be avoided. If moisture is present, FS smoke agent is excessively corrosive, and it will cause skin burns.

7-3.3.5 Smoke-Producing Reactions Involving Ammonia or Amines

Most of the reactions described in this subparagraph were at one time used to produce screening smoke. For many reasons they are not presently so used. Some of these systems do not require atmosphere constituents (such as water vapor) to be effective smoke producers and, therefore, may be useful at high altitudes.

7-3.3.5.1 Ammonium and Amine Salts of Volatile Acids

Ammonium and amine salts of a volatile acid such as HCl can be vaporized by heating. For ammonium chloride the reaction is:

$$NH_4Cl \longrightarrow NH_3 + HCl$$

On cooling, recombination occurs. Amine salts, such as aniline hydrochloride, may be used similarly. Ammonium or amine salts have no effect on metals when dry; however, the presence of water may result in some corrosion. These salts can be handled without danger to personnel.

7-3.3.5.2 Metal Chlorides and Ammonia

Metal chlorides may also be reacted with ammonia or amines to produce smoke. The base must combine with the metal chloride just after dispersion. Other bases such as hydrazine may be used in place of ammonia.

7-3.3.5.2.1 Hydrogen Chloride and Ammonia

The reaction of hydrogen chloride with ammonia is similar to the reaction of a metal chloride with ammonia. This two-gas system produces fine particles of solid ammonium chloride. The smoke formed is considered very visible. Gaseous hydrogen chloride is not very corrosive to metal containers when dry; however, when moisture is present, it is quite corrosive. Ammonium chloride smoke is not corrosive to metals. Hydrogen chloride gas is very irritating and, in moderate quantities, it is toxic. Ammonia gas is also toxic in moderate quantities; however, ammonium chloride smoke is harmless.

7-3.3.5.2.2 Titanium Tetrachloride and Ammonia

The reaction between titanium tetrachloride and ammonia is somewhat complex. First, an ammoniate is formed. This ammoniate is hydrolyzed by water vapor from the atmosphere. Ammonia reacts with the hydrochloric acid gas released during hydrolysis of $TiCl_4$ to give NH_4Cl. Therefore, the system without water vapor is less effective. The reactions for this process are as follows:

$$TiCl_4 + 4NH_3 \longrightarrow TiCl_4 \cdot 4NH_3$$

$$TiCl_4 \cdot 4NH_3 + 5H_2O \longrightarrow Ti(OH)_4 \cdot H_2O + 4NH_4Cl$$

The smoke is a mixture of $Ti(OH)_4 \cdot H_2O$, intermediate hydroxy chlorides of titanium, and ammonium chloride particles.

7-3.3.5.2.3 Silicon Tetrachloride, Ammonia, and Water

The best proportions are two parts silicon tetrachloride, one part ammonia, and one part water, by weight. The reactions are quite complex; first, an ammoniated silicon tetrachloride is formed while at the same time hydrolysis of the silicon tetrachloride occurs to give SiO_2, $2H_2O$, and HCl; and finally, NH_3 combines with the HCl to give NH_4Cl. The reaction sequence is:

$$SiCl_4 + 4NH_3 \longrightarrow SiCl_4 \cdot 4NH_3$$
$$SiCl_4 + 4H_2O \longrightarrow SiO_2 \cdot 2H_2O + 4HCl$$
$$SiCl_4 \cdot 4NH_3 + 4H_2O \longrightarrow SiO_2 \cdot 2H_2O + 4NH_4Cl$$
$$HCl + NH_3 \longrightarrow NH_4Cl$$

7-3.3.5.3 Sulfur Compounds and Ammonia

Sulfur compounds will also react with bases including ammonia and amines. These smoke-producing systems do not require atmospheric constituents to form the smoke particles and, therefore, may be useful at high altitudes.

7-3.3.5.3.1 Sulfur Trioxide and Ammonia or Amines

The smoke is formed by supplying a reactive gas to sulfur trioxide at the time of dispersion. Ammonia and amines have proved successful, and other basic substances, such as hydrazine, hydroxylamine, etc., might be satisfactory. In the case of sulfur trioxide and ammonia, the reactions are:

$$SO_3 + 2NH_3 \longrightarrow SO_2(NH_2)_2 + H_2O$$
$$SO_3 + NH_3 \longrightarrow HSO_3NH_2$$
$$SO_3 + 2NH_3 \longrightarrow NH_2SO_3NH_4$$

All three reactions occur more or less simultaneously. As far as can be determined, the smoke consists of particles of these products.

7-3.3.5.3.2 Chlorosulfonic Acid and Ammonia or Amines

Ammonia and the amines react readily with $HClSO_3$ in much the same manner as with sulfur trioxide; other bases such as hydrazine, hydroxylamine, etc., probably could be substituted. The basic reaction is as follows:

$$HClSO_3 + 3NH_3 \longrightarrow SO_2(NH_2)_2 \cdot NH_4Cl + H_2O$$

Other reaction products might be formed in addition to the products indicated by this reaction.

7-3.3.5.3.3 Sulfuryl Chloride and Ammonia or Amines

Sulfuryl chloride will react with bases such as ammonia and amines to give a better smoke than is formed with water vapor. The following reactions are for sulfuryl chloride and ammonia:

$$SO_2Cl_2 + 4NH_3 \longrightarrow SO_2(NH_2)_2 + 2NH_4Cl$$
$$2SO_2Cl_2 + 7NH_3 \longrightarrow 4NH_4Cl + NH(SO_2NH_2)_2$$
$$3SO_2Cl_2 + 9NH_3 \longrightarrow 6NH_4Cl + (NH)_3(SO_2)_3$$

The first reaction gives sulfamide; the second, aminosulfamide; and the third, trisulfamide. Whether the smoke particles are those products or further reaction products is not known.

7-3.3.6 Sulfur Smokes

Sulfur smokes consist of small particles of elemental sulfur suspended in the air. Sulfur smokes can be produced by methods similar to those used for the production of oil smokes. In addition, sulfur smokes can be made by intimately mixing sulfur and a suitable fuel. Mixtures which have been used include sulfur, sodium nitrate, and charcoal; sulfur, potassium nitrate and charcoal; and sulfur, ammonium nitrate, and charcoal. The sulfur is present in much larger quantities than in black powder; the latent heat of vaporization and fusion of the sulfur absorbs the heat produced by the reaction and, hence, slows the burning rate. The burning rate for this type of mixture depends on the percentage of sulfur.

7-3.3.7 Organic Metallic Compounds

Certain organic metallic compounds can be used for the production of smoke. These compounds are reactive and will burn spontaneously in moist air. The sequence of reaction between an organic metal-

lic compound, water, and oxygen is a highly exothermic reaction between the organic metallic compound and water vapor, yielding a hydrocarbon and metal hydroxide; the heat of this reaction results in the hydrocarbon's burning to form carbon dioxide and water. This reaction for dimethyl zinc is:

$$(CH_3)_2Zn + 2H_2O \longrightarrow 2CH_4 + Zn(OH)_2$$
$$CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O$$

In this case the white particles consist of solid zinc hydroxide particles.

7-3.3.8 Comparison of White Smokes

The total obscuring power, TOP,[32] of a smoke is obtained by multiplying the product of volume, in cubic feet of smoke produced per pound of material, and the reciprocal of the smoke layer, in feet, necessary to obscure the filament of a 40-watt Mazda lamp. The TOP for some white smoke agents, at low altitudes where atmospheric constituents are plentifiul, is given in Table 7-6.

The so-called "standard smoke" is a smoke of such a density that a 25-candlepower light is just invisible when observed through a layer 100 feet thick. A comparison of some white smoke agents at low altitude, where atmospheric constituents are plentiful, in terms of the amount of smoke agent required to produce 1000 cubic feet of standard smoke, is given in Table 7-7.

All of the TOP and standard smoke measurements were made at low altitude, where atmospheric constituents available for reaction with the primary smoke particles were plentiful. The importance of atmospheric constituents is illustrated in Table 7-8 where the number of grams of smoke formed per gram of smoke agent used is tabulated. It is evident, for the agents compared, that WP yields the greatest weight of aqueous solution in equilibrium with air at 75 percent relative humidity per unit-weight of the smoke agent. The ratio for fog oil is unity (1.0) since the fog oil is not hygroscopic and only the agent is available to form the smoke particles. The values do not take into account ingredients which remain behind as residues or otherwise contribute little to the obscuring power. The absolute values will vary with the relative humidity, but change very little with air

TABLE 7-6
TOTAL OBSCURING POWER OF WHITE SMOKES

Chemical	*TOP, ft^2/lb*
White Phosphorus	4600
$TiCl_4 + NH_3$	3030
SO_3	3000
FS	2550
$HCl + NH_3$	2500
HC Mixture	2100
$SiCl_4 + NH_3$	1960
FM	1900
Oleum	1890
$SnCl_4$	1860
$PCl_3 + NH_3$	1600
$PCl_3 + NH_3$	1800
$HClSO_3 + NH_3$	1600
$SiCl_4$	1500
$HClSO_3$	1400
BM Mixture	1400
Berger Mixture	1250
FM + 1,2-Dichloroethane	1235
SO_2Cl_2	1200
$Cl_2 + NH_3$	750
$AsCl_3$	460
Type-S Mixture	460
Crude Oil	200

TABLE 7-7
AMOUNT OF SMOKE AGENTS REQUIRED TO PRODUCE 1,000 CUBIC FEET OF STANDARD SMOKE

Compound	*Amount Required, oz*
Phosphorus	0.060
$FM + NH_3$	0.090
SO_3	0.094
FS	0.110
HC Mixture	0.120
FM	0.150
Oleum	0.151
Crude Oil	2.000

AMCP 706-185

TABLE 7-8
AMOUNT OF SMOKE PRODUCED PER UNIT WEIGHT OF SMOKE AGENT AT 75% RELATIVE HUMIDITY

Agent	*Amount*
Fog Oil	1.0 (does not produce aqueous solution)
Zinc Chloride	2.5 (water vapor absorbed)
Ferric Chloride	3.1 (water vapor absorbed)
Aluminum Chloride	5.0 (water-vapor absorbed)
Phosphorus	7.11

temperature at any one value of the relative humidity. Also, the relative results are not changed. It is important to note that these measurements chiefly concern the obscuring or screening power of the smoke and no consideration is given to other factors which might be important for a signal smoke, tracking aid, or tracking and acquisition smoke.

7-3.4 COLORED SMOKES[33]

Colored smokes, like other smokes, can be produced by four basic methods:

a. Dispersion of finely powdered, colored materials
b. Chemical reactions resulting in the formation of colored particles
c. Detonation of an explosive, thereby scattering colored material, or
d. Volatization and condensation of a colored material.

The first two methods have been found to give smokes of only small volume and dull color. The last two methods, both of which involve the vaporization and condensation of a colored material, have been found feasible only when volatile organic dyes are used as the coloring material. As a result, all colored smoke signals (except black) are based, at present, upon the use of an organic dye.

7-3.4.1 Dyes[34]

Since colored smokes involve vaporization and condensation, constituent dyes are required to be thermally stable and fairly volatile, and to possess the requisite purity of color when disseminated as a smoke. These properties are closely related to the chemical constitution of the dye. No dye was ever specifically developed for smoke application; only those available were considered and tested. In an early investigation of the thermal stability and volatility of dyes, it was concluded that dyes containing amino or substituted amino groups, but not sulfonic groups, were suitable for the production of colored smokes. These conclusions were confirmed and amplified by British investigators in a systematic survey of common dyestuffs. The constitutional characteristics which render a dyestuff suitable for the production of colored smoke were found to be as follows:

a. The molecular weight of the dye should preferably be less than 400, but in no case greater than 450.
b. The dye should be a member of one of the following series: anthraquinone, azine, azo, quinoline, xanthene, or anthrone.
c. The following groups must be absent: sulfonic, hydrochloride, nitro, nitrose, quarternary ammonium, and oxonium.
d. The following groups may be present: amino and substituted amino, alkyl, aryl, chloro, bromo, hydroxy, and alkoxy.
e. The dye must not tend to undergo auto-condensation.

Not all dyes which have the above characteristics will produce satisfactory colored smokes, but some of the many dyes which have been evaluated will produce "excellent" colored smoke clouds. Some of the more satisfactory dyes are listed in Tables 7-9 and 7-10.

In general, the anthraquinone dyes have proved to be superior to all others in producing colored smoke clouds. The azo derivatives have furnished only a few suitable dyes, despite the fact that they constitute the largest class investigated. In no case have the azo dyes been superior to the anthraquinone dyes. The undesirable qualities of the azo dyes are their tendency to flame and their transparency. Among the azine dyes, rosindone and its derivatives give excellent, bright smoke clouds without flaming. Their color range, however, is limited to red and orange. This class of dyes offers

TABLE 7-9
SOME DYES WHICH HAVE BEEN USED IN BURNING-TYPE COLORED SMOKE MUNITIONS

Red Smoke:	*Dye(s)*
	9-diethylamino-7-phenyl-5-benzo (a) phenazinone. Also known as 9-diethylamino rosindone
	1-methylaminoanthraquinone
	1-(2-methoxyphenylazo)-2-naphthol
	2-quinolyl-2-indandione-1,3 (Rhodamine B) plus 1-(4-phenylazo)-2-naphthol
	2-aminoanthraquinone plus 1-methylaminoanthraquinone
	O-tolylazo-o-tolylazo-β-naphthol (Sudan IV); plus 2-quinolyl-2-indandione-1,3 (Rhodamine B); plus auramine hydrochloride
	1-(tolylazoxylylazo)-2-naphthol
Green Smoke:	
	1,8-di-p-toluidinoanthraquinone
	1,4-di-p-toluidinoanthraquinone
	1-methylamino-4-p-toluidinoanthraquinone plus auramine hydrochloride
	1,4-di-p-toluidinoanthraquinone plus dimethylaminoazobenzene
	1,4-di-p-toluidinoanthraquinone plus auramine hydrochloride
	1,4-di-p-toluidinoanthraquinone with quinophthalone (quinoline yellow)
Orange Smoke:	
	1-aminoanthraquinone
	1-amino-8-chloroanthraquinone plus quinizarin
	1-(4-phenylazo)-2-naphthol
	9,10-dianilinoanthracene plus phthaloperinone
	1-(4-phenylazo)-2-naphthol plus 9,10-dianilinoanthracene
Orange-Red Smoke:	
	1-(4-nitrophenylazo)-2-naphthol
Yellow Smoke:	
	Auramine hydrochloride
	1-(4-dimethylaminophenylazo)-2-naphthol
	1-(4-phenylazo)-2-naphthol (Sudan 1) plus either auramine hydrochloride or quinophthalone (quinoline yellow)
	N,N-dimethyl-p-phenylazoaniline

TABLE 7-9 (cont'd)

Blue Smoke:	*Dye(s)*
	1-hydroxy-4-p-toluidinoanthraquinone
	Indigo
	1-amino-2-bromo-4-p-toluidinoanthraquinone
	1-amino-2-methyl-4-p-toluidinoanthraquinone (Alizarin Sapphire, Blue R. Base)
	1,4-dimethylaminoanthraquinone
	1-hydroxy-4-p-toluidinoanthraquinone
	1-methylamino-4-p-toluidinoanthraquinone
	N-(p-dimethylaminophenyl)-1,4-naphtholquinonimine
Violet Smoke:	
	1,4-diaminoanthraquinone
	1,4-diamino-2,3-dihydroanthraquinone
	1,5-di-p-toluidinoanthraquinone
	1-methylamino-4-p-toluidinoanthraquinone plus 2-quinolyl-2-indandione-1,3 (Rhodamine B)
	1-methylamino-4-p-toluidinoanthraquinone plus 1,5-di-p-toluidinoanthraquinone

TABLE 7-10
SOME DYES WHICH HAVE BEEN USED IN EXPLOSIVE-TYPE COLORED SMOKE MUNITIONS

Red Smoke:	*Dye(s)*
	1-(2-methoxyphenylazo)-2-naphthol
	1-methylaminoanthraquinone (Celanthrene Red)
Yellow Smoke:	
	2,4-diaminoazobenzene (Chrysoidine G, base)
	Auramine Hydrochloride
Green Smoke:	
	1,4-di-p-toluidinoanthraquinone (Quinizarin Green) plus quinophthalone (Quinoline Yellow, base) in the ratio of 65/35
	1-4-di-p-toluidinoanthraquinone plus auramine hydrochloride

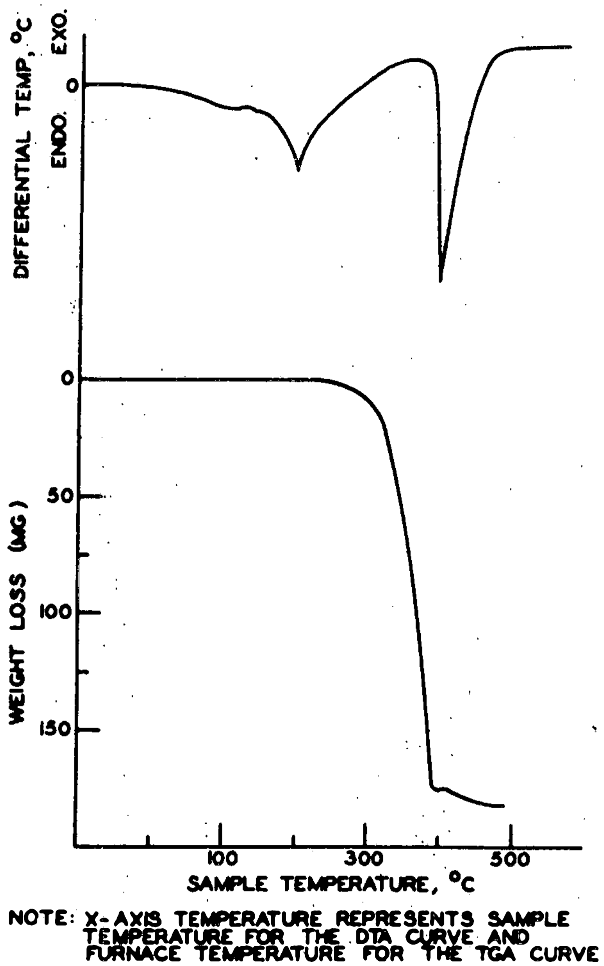


Figure 7-10. Differential Thermal Analysis and Thermogravimetric Analysis Curve for 1,8-dihydroxyanthraquinone

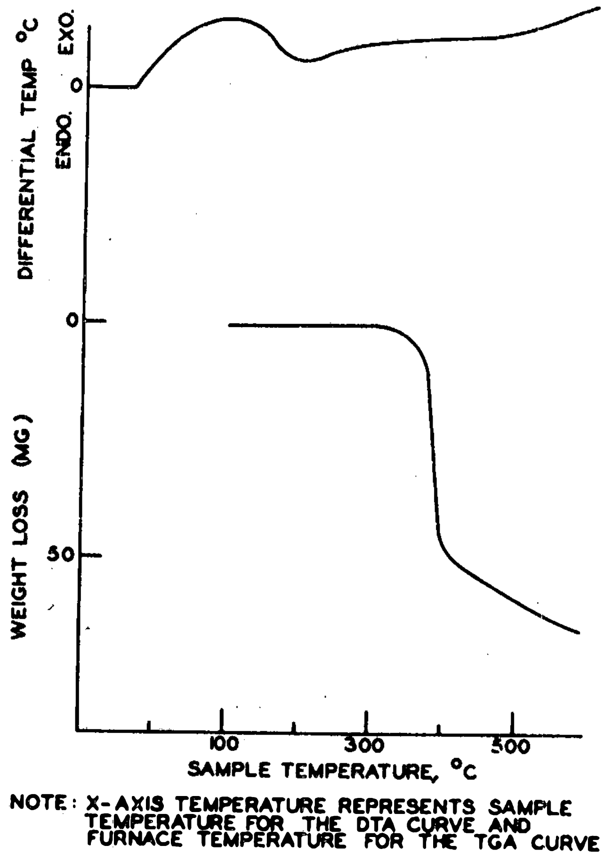


Figure 7-11. Differential Thermal Analysis and Thermogravimetric Analysis Curve for 1,4-di-p-toluidinoanthraquinone

the most promise for future investigation. Several dyes containing sulfonic groups have been tested and, with only one exception, found to be nonvolatile; this exception is the ammonium salt of 2-(2-hydroxy-1-naphthylazo)-1-naphthalenesulfonic acid which gives a fair red smoke. Lakes and other pigments have been found to give no smoke when used in pyrotechnic mixtures. For satisfactory results, the purity of dyes used must be high, since organic impurities are usually volatile and tend to give a muddy-colored smoke. Inorganic impurities are generally either sodium chloride or sodium sulfate and, while they in themselves do not change the color of the smoke, large quantities slow down the burning rate of the smoke mixture and decrease the quantity of smoke available.

Although organic dyes have been widely used in burning- and burst-type colored smoke markers and signals, very little is known about their chemical, physical, and thermodynamic properties at elevated temperatures. In making a choice of dyes, the thermodynamic properties of the compounds—such as heats of fusion, vaporization or sublimation, decomposition, equilibrium vapor pressures, rates of vaporization, and the temperatures at which these phenomena occur—are important. For example, if the compound is thermally stable but has a relatively low vapor pressure so that relatively high temperatures are required for its vaporization, the fuel-oxidant to dye ratio required for optimum vaporization of the dye will not allow the munition to contain the amount of dye necessary to produce an acceptable volume of colored smoke. If the dye can be vaporized at a low tem-

perature but the differential between the temperature for vaporization and the temperature for decomposition is not large, the dye to fuel ratio increases but the possibility of decomposition of the dye is also greatly increased. In general, therefore, the dyes utilized must be thermally stable and vaporize without decomposition at intermediate temperatures.

The volatilization properties of organic dyes proposed for use in pyrotechnic smoke mixtures were studied by differential thermal analysis (DTA) and thermogavimetric techniques.[35,36] The dyes evaluated by these techniques can be classified into three groups.

The materials in Group 1 exhibit an initial weight loss, the rate of which increases as a function of temperature. They do not have an inflection in their thermogravimetric curves until they have undergone a weight loss of 65 to 100 percent. An examination of the DTA curves for these materials generally indicates an endothermal reaction followed by an exothermal trend, and, finally, an endothermal region. Over these temperature ranges the following phenomena were observed: fusion, the evolution of small quantities of vapor, and boiling.

Compounds in Group 2 show an initial weight loss of from 30 to 50 percent, followed by a sharp break in the thermogravimetric curve, after which the rate of weight loss is generally slower. The thermogravimetric curves for Group 3 materials indicate an initial weight loss of only 2 to 20 percent prior to an inflection.

In general, the materials in Group 1 possess the thermal properties of stability and volatility required for satisfactory functioning in pyrotechnic smoke items. For most of these materials, as shown in Figure 7-10 for 1,8-dihydroxyanthraquinone, no weight loss occurs before fusion; once the boiling point is approached the rate of weight loss increases uniformly with temperature. The absence of a break or point of inflection in the thermogravimetric curves for the Group 1 materials, is indicative in this case, of vaporization. Group 2 materials do not vaporize appreciably. As shown in Figure 7-11, 1,4-di-p-toluidinoanthraquinone, a standard dye used for the production of blue smoke, exhibits approximately a 30 percent initial weight loss during which a point of inflection occurs. It is postulated that this material reacts to form an effective color product in the temperature region of 350°C to 440°C. If, however, the temperature of the dye is not carefully controlled, it decomposes further to form a volatile red product. In general, the dyes in Groups 2 and 3 do not perform satisfactorily. They fail to vaporize appreciably and the irregularities in the differential thermal analysis curves indicate the occurrence of reactions and/or decomposition. The temperature produced by the reaction must be sufficiently high to rapidly vaporize the dye but not excessive so as to cause decomposition of the dye, or flaming. A cooling agent such as sodium or potassium bicarbonate may be added to the fuel mix to regulate the burning rate. Binders are sometimes used to produce a composition that is easier to handle and process.

The properties and structures of certain selected dyes are as follows:

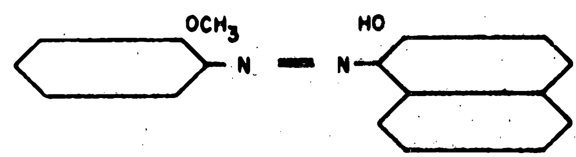
Dyes Selected by the British as the Best Agents Available for the Production of Colored Smokes by Explosion, Using PETN (pentraerythritol tetranitrate) for the Explosive:

Red: **o-methoxybenzene-azo-β-naphthol (Brilliant Fat Scarlet)**

Molecular Weight: **278**

Components: **o-Anisidine → β-naphthol**

$C_{17}H_{14}N_2O_2$



Properties, Description: **Red paste; separates from glacial acetic acid in red crystalline powder, m.p. 180°C. H_2O—insoluble. Alcohol—red solution on boiling. H_2SO_4—bluish-red solution, red precipitate on dilution.**

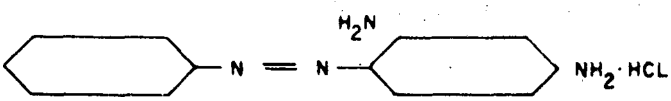
Commercial Names: **Oil Vermilion (W), Sudan R (A), Brilliant Fat Scarlet B (SCI), Pigment Purple (MLB).**

Yellow: 2,4-Diaminoazobenzene (Chrysoidine G, base)

Molecular Weight: 212

Components: Aniline—m-Phenylenediamine

$C_{12}H_{13}N_4Cl$



Properties, Description: Reddish-brown crystalline powder or large black shining crystals with a green luster (latter contain the homologs from o- and p-toluidine). H_2O—orange-brown solution. Alcohol—orange-brown solution. Ether—insoluble. HCl to aqueous solution: brown-yellow gelatinous precipitate consisting of hair-like needles. NaOH—red-brown precipitate of chrysoide base, m.p. 117°C, sparingly soluble in H_2O, soluble in ether, alcohol, or benzene. H_2SO_4—brown-yellow solution, cherry-red to orange solution on dilution.

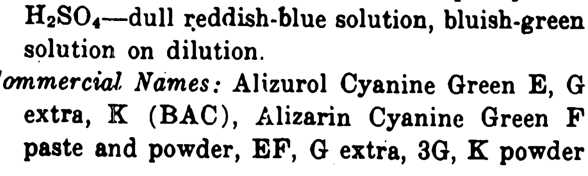
Commercial Names: Chrysoidine G (CAC), (DuP), (Gy), (SCI), (MLy), (By), (GrE), Chrysoidine Base (CHC), (CV), (JWL), (LBH), (W), (NAC).

Green: Mixture of 1,4 di-pi-toluidinoamino-anthraquinone (Quinzarin Green) and quinophthalone (Quinoline Yellow, base) in the ratio of 65/35.

Molecular Weight: 418 (Quinzarin Green)

Components: leuco-Quinzarin (or 1,4-Dichloroanthraquinone) and p-Toluidine.

$C_{28}H_{20}N_2O_2Na_2$



Properties, Description: Bluish-green powder. H_2O—bluish-green solution. HCl—dark soluble precipitate. NaOH—dark soluble precipitate. H_2SO_4—dull reddish-blue solution, bluish-green solution on dilution.

Commercial Names: Alizurol Cyanine Green E, G extra, K (BAC), Alizarin Cyanine Green F paste and powder, EF, G extra, 3G, K powder and paste (By), Alizarin Brilliant Green EF, G conc. (LBH), Solway Green E, EF, GM (SDC), formerly Kymric Green E, G extra (SDC).

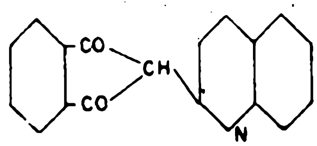
A mixture of 55% 1,4-dimethylaminoanthraquinone (Brilliant Blue G, M.W. 266) and 45% Quinophthalone (Quinoline Yellow Base) is also used to produce green smokes of an emerald green color. The mixture of Quinzarin Green and Quinoline Yellow (base) produces a color approaching the green of the spectrum.

Quinoline Yellow: Mixture of symmetrical quinophthalone or 2-quinolylindandione, with small quantities of iso-quinophthalone, or unsymmetrical quinophthalone or 2-quinaldylenephthalide.

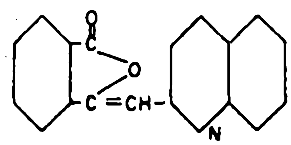
Molecular Weight: 273

Components: Quinaldine and phthalic anhydride.

$C_{18}H_{11}NO_2$



Quinophthalone



iso-Quinaphthalone

Properties, Description: Yellow powder, crystallizes from boiling alcohol in thin golden-yellow needles, m.p. 240°C; iso-quinophthalone is more soluble in alcohol and crystallizes in orange-yellow prisms, m.p. 187°C. H_2O—insoluble. Alcohol—sparingly soluble with a yellow color. H_2SO_4—yellowish-red solution, yellow flocculent precipitate on dilution.

Commercial Names: Quinoline Yellow spirit-soluble (H), (S), (RF), (A), (B), (By), (K), Brilliant Fat Yellow C (SCI). Quinophthalone

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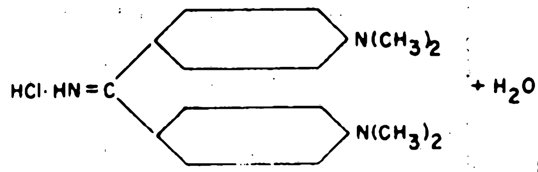
Dyes Selected by the U.S. as Satisfactory Agents for Producing Burning Type Smokes:

Yellow: Auramine—Hydrochloride of tetramethyldiamino-diphenyl-ketonimine.

Molecular Weight: 267

Components: Tetramethyldiamino-diphenyl methane, ammonium chloride, and sulfur.

$C_{17}H_{22}N_3Cl + H_2O$



Properties, Description: Sulfur-yellow powder. H_2O—bright yellow solution, readily decomposed on boiling. Alcohol—yellow solution. NaOH—white precipitate of Auramine base, m.p. 130°C, soluble in ether. H_2SO_4—colorless solution, pale yellow color on dilution.

Commercial Names: Auramine (H), (Gy), (S), (SCI), (StD), (A), (B), (By), (C), (L), (MLB), (tM);
Auramine O (BDC), (DuP), (Gy), (S), (SCI), (StD), (B)
O conc. (LBH), DuP) NO(CN)
II (BDC), (LBH), (S), (A), (B) 2 (StD)
NAC (NAC) OE (B)
OO extra conc. (SCI), (StD) extra conc. (MLB)
Fat Yellow A (SCI)
Canary Yellow (Gr E)

Green: 1,4-di-p-toluidinoanthraquinone with auramine hydrochloride

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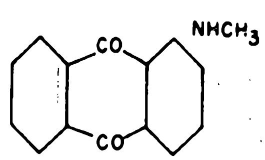
Red: 1-Methylaminoanthraquinone (Celanthrene Red)
Molecular Weight: 237



Commercial Name: Duranol Red B(BDC)

Products Currently Used for Colored Smoke Compositions:

Green: 1-4-di-p-toluidinoanthraquinone and Auramine

Red: 1-Methylamino anthraquinone

Yellow: Beta-naphthalene-azo-dimethylaniline and Auramine $C_{18}H_{17}N_3$
Molecular Weight: 275

7-3.4.2 Fuels[33,37]

The number of combustibles that are satisfactory in colored smoke mixtures is very limited and includes sulfur, thiourea, and sugars such as lactose, sucrose, and dextrose. Dextrin, starch, and lampblack can be used, in part, to replace the above materials but results have not always been satisfactory. Among the sugars, lactose has been found to be the most desirable. Sucrose and dextrose (corn sugar) have the disadvantage of being somewhat hygroscopic, and a small percentage of starch is usually added to enable their handling under conditions of high humidity. Potassium chlorate and sugar are usually mixed in about equal parts. Although such a fuel mixture contains an excess of sugar, the excess has been found necessary to secure proper action of the smoke ingredients. For slow-burning colored smoke mixtures, a fuel composed of sulfur and potassium chlorate, in stoichiometric proportions, has been found to be highly satisfactory.

With either sucrose or lactose as fuel, the gaseous products formed are carbon dioxide and water vapor:

$$C_{12}H_{22}O_{11} + 8KClO_3 \longrightarrow 8KCl + 12CO_2 + 11H_2O$$

Lactose would yield an additional mole of water when oxidized by potassium chlorate.

7-3.4.3 Oxidants[33,37]

A large number of fuel-oxidant mixtures have been investigated. The oxidizing agents studied include chlorates, perchlorates, permanganates, nitrates, nitrites, peroxides, and oxides. However, the only satisfactory oxidizing agent found thus far, despite its friction-sensitivity, has been potassium chlorate. Potassium nitrate might be used to replace potassium chlorate in colored smoke mixtures if a very stable dye such as 1-methylaminoanthraquinone is used. Even with this dye, only slow-burning grenades have been produced using potassium nitrate. With most dyes, a nitrate is always less desirable than a chlorate, and

nitrates have been found unsatisfactory with auramine hydrochloride and indigo. Nitrates, therefore, should not be substituted for the chlorates in colored smoke munitions unless a special condition, such as a shortage of chlorate, makes it necessary.

7-3.4.4 Cooling Agents[33,37]

Cooling agents may be added to regulate the burning rate of the fuel and to lower the temperature sufficiently to prevent excessive decomposition of the dye with resultant decolorization or strong flaming. The best cooling agents have been found to be sodium bicarbonate or potassium bicarbonate. Potassium bicarbonate decomposes at a higher temperature than sodium bicarbonate and is, therefore, more suitable for fast-burning types of colored smoke mixtures. Sodium bicarbonate has been found better for the slower-burning mixtures. Other cooling agents which have been investigated are the ammonium salts such as the chloride, bromide, oxalate, carbonate, sulfate, sulfite, thiocyanate, and tartrate. These have been found to work with varying degrees of success but most of them have the disadvantage that, upon condensation, they form white smokes which dilute the color of the dye smoke. Inert diluents—such as Fuller's earth, calcium carbonate, and kaolin—have often been added to smoke mixtures to retard the burning rate and reduce flaming.

7-3.4.5 Binders

Graphite, zinc oxide, and linseed oil have been used for some applications but in most cases no binder has been used and the composition has been consolidated under pressure. Because of the problems associated with the loading of smoke mixtures, some work has been directed toward the development of a plastic-bonded smoke mixture.[38] None of the plastic-bonded smokes have been standardized. The use of a binder such as polyvinyl acetate[39] would be advantageous because: (1) it contributes few undesirable qualities to the smoke, (2) it binds smoke mixtures into a hard, tough, nonbrittle mass having excellent water and shock resistance, (3) it produces a formulation which withstands high and low temperature surveillance with negligible change, (4) it is safe, nontoxic, and easily handled, (5) it is available at low cost and in quantity, and (6) it eliminates the necessity for consolidation under pressure. Other plastics which have been considered include various monomers and polymers of acrylic and vinyl plastics, polyamines, and epoxy-type resins.

7-3.4.6 Evaluation of Colored Smokes

Of the original colored smokes used; red, green, yellow, and violet were found to be the most suitable. These colors were most perceptible against the various backgrounds and displayed optimum visibility at a considerable distance. Further, they were least affected by the light-scattering properties of the atmosphere. Blue was found unsuitable for signaling purposes because of excessive effect of light scatter.

A number of different methods have been used to measure the quality of a colored smoke. In many cases, they were merely observed at various distances. More quantitative methods involve the use of Munsell color charts[40] and colorimeters. Extended chroma Munsell color charts developed by the National Bureau of Standards were successfully used in measuring the color of colored smoke clouds.[41] Munsell color cards were designed and used in field measurements. The Munsell color data were converted to the internationally accepted C.I.E. system of color representation for evaluation.

7-3.4.7 Sensitivity of Colored Smoke Mixtures[42]

Most of the colored smoke mixtures which have been used, with the exception of the yellow smoke mixture containing auramine, may be considered satisfactorily insensitive to friction and impact under the conditions encountered in normal loading operations. Yellow smoke mixtures containing auramine are impact-sensitive, and require more care in handling and loading. Smoke mixtures containing 1-(4-dimethylaminophenylazo)-2-naphthol are markedly less sensitive to impact and friction than mixtures containing auramine. Ignition test results show that colored smoke compositions can be ignited by hot surfaces—and no doubt by open flames and other direct heat sources—of comparatively low temperature. Following ignition, dust

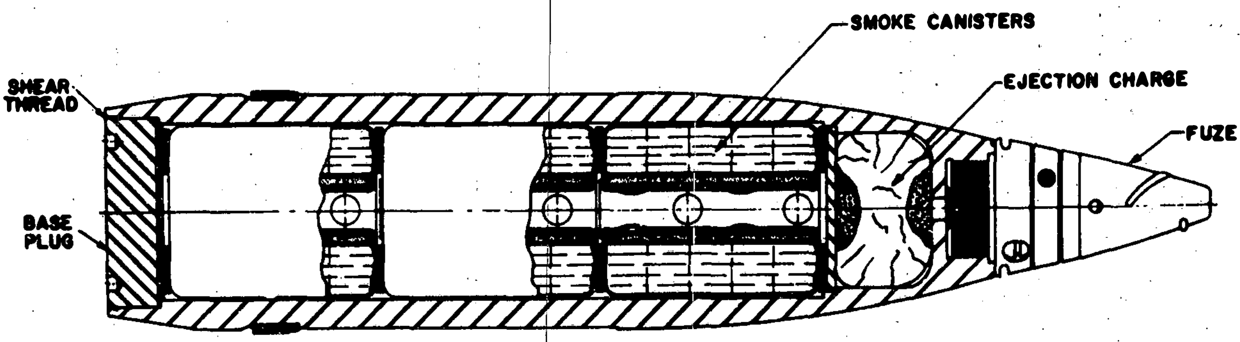


Figure 7-12. 105 mm M84 Colored Smoke Projectile

clouds or dispersions of these powders are capable of producing dust explosions.

7-3.4.8 Toxicity of Colored Smoke Mixture

As standardized, the colored smoke clouds are nontoxic in ordinary field concentrations. In general, toxic materials should not be employed as ingredients in signaling and screening munitions. It has been reported[43] that certain dyes exhibit carcinogenic characteristics which should be guarded against when they are used. The problem in determining whether or not a dye is a carcinogenic hazard is complex because the products of metabolism of the dye must also be considered for carcinogenic activity even though the original dye may be harmless. The hazards involved in handling carcinogenic materials are not in the quantities involved but in the frequency of exposure no matter how small the dosage.

One of the smoke dyes of great interest to the Army, Indanthrene Golden Yellow GK, has been tested and found to be not carcinogenic but it is closely related to 3,4,8,9-dibenzpyrene (Idanthrene Golden Yellow without the two oxygens) which is known to be a very potent carcinogen. If this compound should be present or formed by a process of reduction as an impurity in even as small a quantity as .01% it would present a considerable hazard. Red dye, 1-methylaminoanthraquinone, has not been tested for carcinogenicity but has the possibility of being a potential liver carcinogen. Two other smoke dyes, Sudan Orange R (1-phenylazo-2-naphthol) and 1-(2-methoxyphenylazo)-2-naphthol are reported as carcinogenic. Blue dye, 1,4-diamino-2,3-dihydroanthraquinone, has not been tested but is expected to be relatively safe by its structure. Diethylamino Rosindone might undergo metabolic reduction in the body to yield carcinogenic β-naphthylamine. Green smoke dye 1,4-di-p-toluidinoanthraquinone is on the current approved list for drugs and cosmetics (Food and Drug Administration).

Before experimentation with a particular dye is undertaken, it is important to gain all available information pertaining to the potential hazards involved in its use.

7-3.4.9 Typical Devices

Colored smoke mixtures have been used in hand and rifle grenades, mortar and artillery projectiles, float signals, rockets, smoke bombs, and similar munitions. As shown in Figure 7-12, a smoke composition is often contained in a canister which is ejected from the projectile when the fuze functions. The ejection charge ignites the starter mixture which, in turn, ignites the smoke mixture. This device contains three canisters which are ejected from the base of the projectile on air burst. Each canister contains from 380 to 410 grams of either yellow, red, green, or violet smoke mixture. Many other smoke-producing items, such as grenades, etc., are also based on the canister as shown in Figures 7-13 and 7-14. Characteristics of these devices are given in Tables 7-11 and 7-12.

7-3.4.10 Direct Volatilization of Dye

Colored smoke clouds are also produced by direct volatilization of dye in the thermal generator-type munitions (separate dye and fuel compartments). The dye should preferably be a crystalline compound and have a melting point

TABLE 7-11
CHARACTERISTICS OF TYPICAL EJECTION-TYPE COLORED SMOKE DEVICES

Characteristic	*4.2-in. Colored Smoke Projectile*	*M18 Colored Smoke Hand Grenade*
Dimensions, in.	Overall—4.2 dia by 20 long (approx.) Canister—3.7 dia by 9.3 long (approx.)	2.5 dia by 4.5 high Six smoke emission holes
Weight	Projectile—23 to 24.5 lb Ejection charge—25 g Grade A black powder 35 g infallible powder	11.5 oz make mixture
Fuze	M54 Time and SQ	M201A1 1.2 to 2 sec delay
Propellant	M6	
Loading Pressure	18000 lb/in.^{2}	
Smoke Duration		50-90 sec
Applications	Time-fuzed for air-burst signaling and/or base-ejected for marking ground positions. Uses red, yellow, green or violet colored smoke for signaling, spotting, or outlining a position	Grenade is thrown or launched from a rifle or carbine by using a M2A1 grenade projection adapter. Uses red, yellow, green, or violet colored smoke for signaling
Visibility	Very good	Easily identified at altitude of 10,000 feet against background of green and brown; clearly seen at a distance of three miles.

under 150°C, or a melting point of 100°C, when mixed with a small proportion of a melting-point depressant such as diphenylamine (less than 25 percent is necessary). The dye should be stable for three to four minutes at temperatures of 50°C to 100°C above its melting point. The dye 1-(4-phenylazo)-2-naphthol—called commercially by a variety of names, i.e., duPont Oil Orange, Sudan Orange, Federal Smoke Orange-E, and 1-(O-tolylazo)-2-naphthol (Calco Oil Orange Y-293)—produces good orange smoke clouds but varies in quality depending upon the commercial source. The dye 1-xylylazo-2-naphthol (Calco Oil Scarlet II; National Oil Scarlet 6-G) gives a much redder cloud but the addition of 20 percent duPont Oil Yellow N (N, N-dimethyl-p-phenylazoaniline) gives a satisfactory color. The dye duPont Oil Yellow N produces a brilliant yellow colored smoke. Mixtures of blue and orange dyes, such as Calco Oil Orange Y-293 and Calco Oil Blue NA (1,4-diamylaminoanthraquinone), give a brown-orange or brown-rose cloud. Blue smoke results from using only 25 percent Calco Oil Orange Y-293. With a 75 percent mixture of National Oil Scarlet 6-G and Calco Oil Blue NA, the color has the appearance of a mixture of orange and violet or tan and violet. Larger percentages of scarlet result in a rose-colored cloud and smaller percentages result in blue smoke. A mixture of the dye 1-(2-methoxyphenylazo)-2-naphthol (Federal Signal Red A)

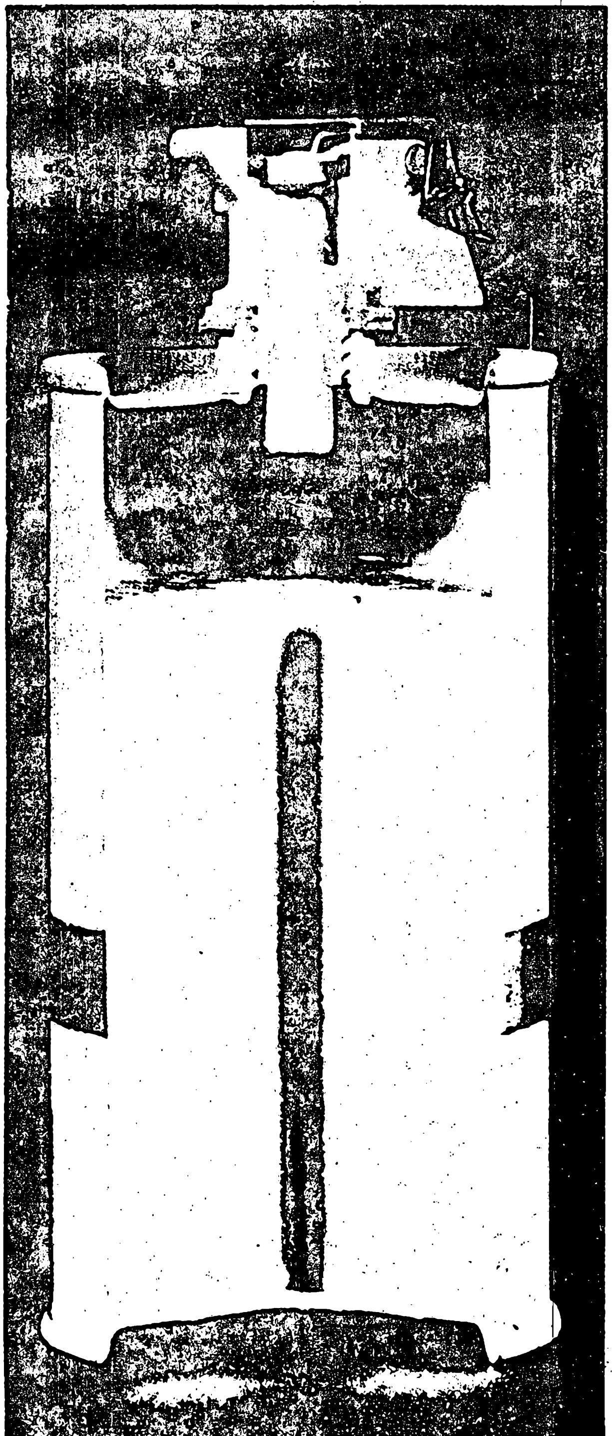


Figure 7-13. M18 Colored Smoke Hand Grenade

with Calco Oil Blue NA gives a blue-gray cloud for all proportions tried. The dye Monoazo Red (duPont) gives much the same result.

7-3.4.11 Colored Smoke from Solution of Dyes[32]

A third method of producing colored smoke clouds is by volatilization of the dyestuff from solution, usually by means of the hot exhaust of a motor. Early attempts to use colored smoke trails from the exhaust of an airplane engine employed a mixture of SAE-10 oil (flushing oil) and dye. Carbon tetrachloride has also been used in place of the oil, but is not recommended. Ten pounds of dye are mixed with two gallons of the oil to a smooth, pasty solution and then diluted with an additional five gallons of flushing oil. The dyes recommended are Oil Purple AB, Oil Blue-Green O, Oil Red EGN, and Oil Orange 2311 [1-(4-phenylazo)-2-naphthol].

The principal difficulty is the low solubility of the dyes in oil. A solvent composed of one part of carbon tetrachloride to four parts of SAE-10 oil is not satisfactory due to congealing of the solution. The use of hexachlorobutadiene as solvent, however, is considered successful in that the resulting mixture of dyestuff and solvent is extremely fluid and has no tendency to congeal. Azo dyes are found to be the most satisfactory. These are Oil Yellow (4-(0-tolylazo)-2-methylaniline), Oil Scarlet 6-G (1-xylylazo-2-naphthol), Oil Red O, and Oil Green Q-261.

Further tests indicate that solutions of dye in hexachlorobutadiene, diluted with SAE-10 oil, are unsatisfactory due to the gelling of the mixture within a few hours after mixing. Solutions prepared with fifteen to eighteen pounds of dye, two to three gallons of trichlorobenzene, and three gallons of SAE-10 oil are found to be satisfactory. No gelling of the solution is noted after six to eight days.

Oil smoke is also produced in a wide variety of colors and shades using the following oil-soluble dyes either as such or in admixture:

Oil Blue NA (1,4-diamylaminoanthraquinone)
Oil Blue RA [N-(p-dimethylaminophenyl)-1,4-naphthoquinonimine]
Oil Red N-1700 [1-(tolylazoxylylazo)-2-naphthol]

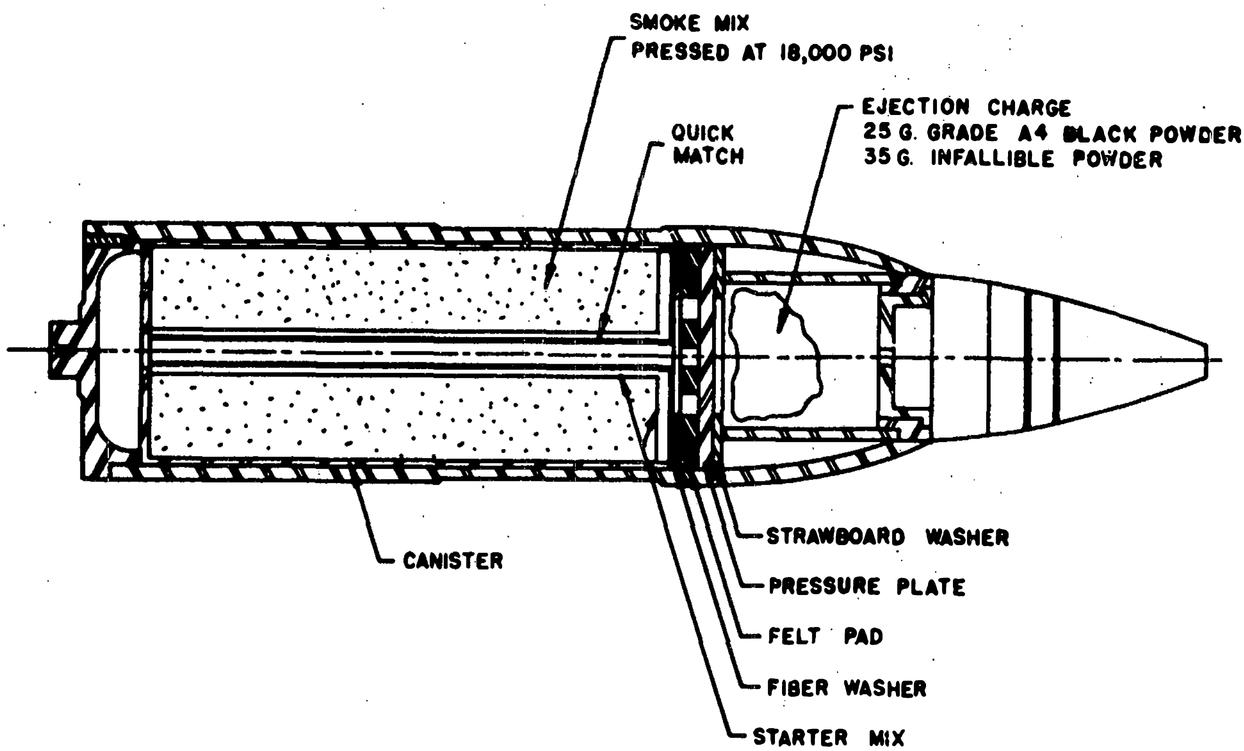


Figure 7-14. 4.2-in. Colored Marker Projectile, Colored Smoke, E75

Oil Orange Y-293 [1-(o-tolylazo-2-naphthol]
Oil Yellow 7463 [N, N-dimethyl-p-phenylazoaniline]
Gas Green CG (1,4-di-p-toluidinoanthraquinone)

The maximum effect with the minimum quantity of dye is obtained by adding about five percent of the dye dissolved and/or suspended in oil dispersed through a point-type spray nozzle. The dye is added at a point in the oil smoke exhaust where the temperature can be varied between 400°C and 800°C. By controlling the temperature within approximately 50°C limits, a fairly constant shade is obtained with each dye. By using different temperature bands, variations are obtained in the shade of smoke produced from a given dye. The efficiency of color production, however, appears to be equivalent in all cases. The shade changes which result from variations of temperature are due, at least in part, to the changes in color of the basic smoke. All the dyes, with the exception of Oil Blue RA and Oil Red N-1700, are found to produce the best results between 450°C and 700°C. Oil Blue RA is used successfully at 400°C to 550°C but shows a complete loss of color at 560°C. Oil Red N-1700 produces the best results between 550°C and 625°C. Water solutions of Auramine and Red Y Supra Conc. (Safranine) are used effectively to produce colored oil smokes. Water spray added to the oil cloud does not appear to have any injurious effect. Water solutions of Blue FFB, New Blue N (Methylene Blue), and Magenta XX fail to produce color under the conditions of these experiments.

7-3.4.12 Black Smoke[33,44]

Black dyes do not, in general, give satisfactorily dense black smokes. Such smokes are generally produced by burning of hydrocarbons such as phenanthrene or anthracene. The addition of an-

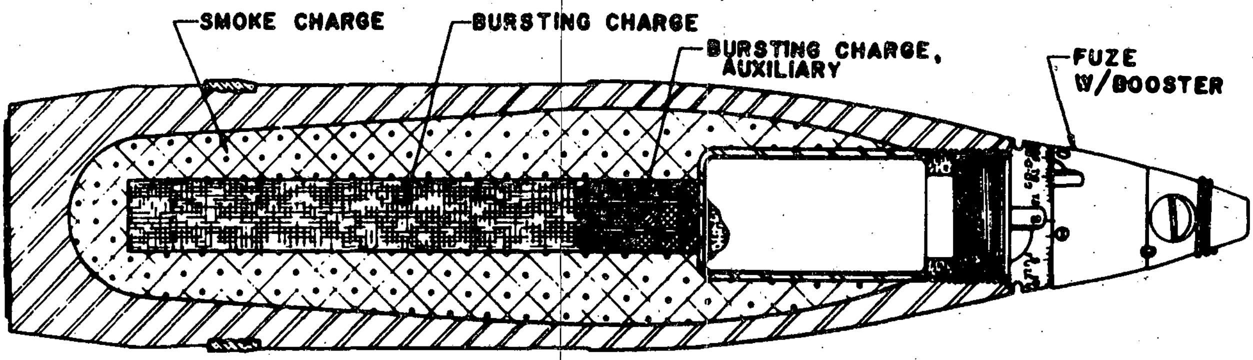


Figure 7-15. 105 mm M1 Colored Marker Projectile

TABLE 7-12
BASIC DIFFERENCES BETWEEN THE COLORED MARKER AND BASE-EJECTION SMOKE PROJECTILES FOR 105 mm GUN

	HE Colored Marker	*Base-Ejection Colored Smoke*
Build-up period of colored cloud	Effective instantaneous	Over a period of from 1-2 min
Density of cloud	Highly saturated	Wispy
Duration of cloud	Average 65-85 sec	75-120 sec
Size of cloud	Approx. 40 × 60 ft	Streamer approx. 4 ft across
Lethality of round	May be lethal (fragments)	Nonlethal
Fuzing of round	MTSQ & VT fuzing	MTSQ fuzing only
Weight of round	Equal to 105 mm HE round	Lighter than 105 mm HE round
Ranging of round	Similar to 105 mm HE round	Canister impacts up to 150 ft away from impact point of projectile body

thracene or naphthalene to HC smoke mixtures also produces black smoke. The oxidizing agent generally used is potassium perchlorate.

7-3.4.13 Explosive-Type Colored Smoke Bursts[45,46]

In addition to the colored smoke dissemination methods discussed in the previous paragraphs, there is the method that produces its effect through the action of an explosive burster. Both propellants and high explosives are used for this purpose. For example, a colored smoke burst can be obtained by using a mixture of approximately equal parts of dye and EC powder. This mixture is detonated with an appropriate detonator or booster charge, the resulting explosion giving a large puff of colored smoke. Colored smoke clouds are also obtained from a mixture of a salt and a dye disseminated by a central high-explosive burster of baratol, amatol, 60 mm ignition powder, Composition B, or others. The use of a salt dilutent is one procedure for producing controlled nuclei on which the dye may condense. Cast or pressed dye, along with a central burster, is also used to produce colored clouds. The basic performance differences between dissemination of colored smoke by an item using an explosive burster and by a munition using burning-type smoke mixtures are tabulated

1400/1710

in Table 7-12. The 105 mm Colored Marker Projectile, referred to in the table, is shown in Figure 7-15.

The dyes that are satisfactory for dissemination by an explosive charge include the same dyes as those used in the burning-type colored smoke munitions. Also, many azo-type dyes which do not perform well in burning smoke munitions give very good smoke clouds when disseminated by EC powder. Among the best dyes for explosive munitions are 1-(2-methoxyphenylazo)-2-naphthol for red, 1-(4-nitrophenylazo)-2-naphthol and 1-(4-phenylazo)-2-naphthol for orange, and 4-phenylazo-m-phenylenediamine for yellow.

7-3.4.13.1 Propellant Bursters[47]

Several propellants have been studied for use as bursters, the EC powder mentioned above showing the greatest promise. Various methods of loading EC powder and dye in a projectile have been tried as follows:

a. Mixing the dye and EC propellant powder intimately before loading the projectile,
b. Coating the projectile wall with melted dye and placing the EC powder in the central cavity,
c. Filling the projectile with melted dye and then drilling out a core for EC powder, and
a. Loading the projectile with approximately equal increments of dye and EC powder in alternate layers.

The last method, in which alternate layers of dye and EC powder are used, was found to be the best. The alternate-layer method of loading with EC powder was found to be superior to bursters of either TNT or tetryl. The burster explosive used is a mixture similar to amatol loadings, consisting of 27.8 percent ammonium picrate and 72.2 percent ammonium nitrate.

7-3.4.13.2 High Explosive Bursters

Sufficient explosive must be included in the burster charge so that when it is detonated, it will break the projectile apart without causing excessive dispersion and/or burning of the filler. The products of explosion must be compatible with the dye used. The color of many dyes is influenced by acidity. For many dyes baratol has proved to be satisfactory. The method for determining the weight of a burster used in colored marker projectiles was derived by assuming that the energy of the explosive charge is proportional to the strain energy required to burst the projectile. In order to simplify calculations, conversion factors and constants are included in a dimensionless factor K. The weight of burster required is given by the empirical formula:

$$w_c = KW(Y + U)eK' \tag{7-7}$$

where

w_c = weight of explosive required (including initiator), g
$K \doteq$ a constant, 11.4×10^{-6} to 11.4×10^{-5}, depending on caliber and explosive used (the exact K can be found by empirical evaluation only)
W = weight of steel components of projectile (excluding fuze and base), lb
Y = yield stress of projectile steel, psi
e = strain elongation at fracture, %
U = ultimate strength of projectile steel, psi
K' = ratio of caloric value of a standard explosive to explosive to be used. For instance, if value of tetryl is 1,100 cal/g and baratol is 900 cal/g the formula would be:
$w_c = KW(Y + U)e(11/9)$

Burster charges designed by this method have functioned favorably. The quantity $(Y + U)e$ is roughly equal to twice the strain energy absorbed by one cubic inch of steel.

7-3.4.14 Typical Mixtures

Typical colored smoke mixtures, including a few white and black smokes, are shown in Table 7-13.

7-3.5 AGENT AEROSOLS

Because of their nature, a detailed discussion of the dissemination of agent aerosols is beyond the scope of this handbook. In general, the principles and methods applicable to the dissemination of a colored smoke agent are applicable to the dissemination of an agent aerosol.

TABLE 7-13
TYPICAL SMOKE COMPOSITIONS

Type	*Composition, %*		*Application*	*Typical Devices*
WHITE:				
HC-Type C	Hexachloroethane	45.5	Screening	Smoke pots
	Zinz Oxide	47.5	and	Smoke bombs
	Aluminum (grained)	7.0	Signaling	Grenades
Modified HC	Hexachlorobenzene	34.4	Screening	Smoke
	Zinc Oxide	27.6	and	projectiles
	NH_4ClO_4	24.0	Signaling	
	Zinc Dust	6.2		
	Laminac w/catalyst	7.8		
Modified HC	Dechlorane	33.9	Screening	Smoke
	Zinc Oxide	37.4	and	projectiles
	NH_4ClO_4	20.5	Signaling	
	Laminac w/catalyst	8.2		
Plasticized White	White Phosphorus	65.0	Screening	Chemical
Phosphorus (PWP)	Plasticizer	35.0	(antipersonnel)	mortar projectiles
	(Neoprene 100 parts)			
	(Carbon 75 parts)			
	(Zylene 44 parts)			
	(Litharge 15 parts)			
BLACK:				
	$KClO_3$ (200 mesh)	52.0	Screening	Grenades, etc.
	Anthracene (40 mesh)	48.0		
COLORED:				
Red	Dye-MIL D-3718	40.0	Signaling	Navy floating
	$KClO_3$	24.0		drift signal
	$NaHCO_3$	17.0		
	Sulfur	5.0		
	Polyester resin	14.0		
Red	1-methylamino (AQ)*	45.0	Signaling	Rocket type
	1,4-di-p-toluidino (AQ)*	3.0		parachute
	$KClO_3$ (23μ)	35.0		ground
	Sugar, fine (11μ)	17.0		signals
Red	1-(methoxyphenylazo)- 2-naphthol	80.0	Air marker Marking	90 mm Red marker
	NaCl	20.0	ground targets	projectile

* (AQ)—Anthraquinone

TABLE 7-13 (cont'd)

Type	Composition, %		Application	Typical Devices
Red	Dye (R)	40.0		
	$KClO_3$	28.0	Signaling	Improved
(plastic)	$NaHCO_3$	23.0		grenade
	Sulfur	5.0		fillings
	Polyvinyl acetate in ethyl acetate	3.0		
Yellow	Benzanthrene	32.0	Signaling	Rocket type
	Indanthrene GK	15.0		parachute
	$KClO_3$ (23μ)	30.0		ground
	Sugar, fine (11μ)	20.0		signals
	$NaHCO_3$ (20μ)	3.0		
Yellow	Auramine Hydrochloride	40.0	Air marker, etc.	90 mm yellow
	NaCl	60.0		marker projectile
Yellow	Dye (Y)	40.0	Signaling	Improved
(plastic)	$KClO_3$	29.8		grenade
	$NaHCO_3$	23.2		fillings
	Polyvinyl acetate in ethyl acetate	7.0		
Green	1,4-di-p-toluidino (AQ)*	28.0	Signaling	Rocket type
	Indanthrene GK			parachute
	(golden yellow)	12.0		ground
	$KClO_3$ (23μ)	35.0		signals
	Sugar, fine (11μ)	23.0		
	$NaHCO_3$ (20μ)	2.0		
Green	Dye (G)	40.0	Signaling	Improved
(plastic)	$KClO_3$	26.0		grenade
	$NaHCO_3$	24.0		fillings
	Sulfur	6.0		
	Polyvinyl acetate w/ethyl acetate	4.0		
Violet	Violet dye,		Signaling	Rocket type
	Spec. MIL-D-3691	47.5		parachute
	$KClO_3$ (25μ)	28.0		ground
	Sugar, fine (10μ)	18.0		signals
	$NaHCO_3$ (20μ)	4.5		
	Asbestos	2.0		
Orange	8-chloro-1-amino (AQ)*	39.0	Signaling	Grenades
	Auramine	6.0		
	$KClO_3$	22.3		
	Sulfur	8.7		
	$NaHCO_3$	24.0		

* (AQ)—Anthraquinone

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212(S)	Fuzes, Proximity, Electrical, Part Two (U)
213(S)	Fuzes, Proximity, Electrical, Part Three (U)
214(S)	Fuzes, Proximity, Electrical, Part Four (U)
215(C)	Fuzes, Proximity, Electrical, Part Five (U)
242	Design for Control of Projectile Flight Characteristics
244	Section 1, Artillery Ammunition--General, with Table of Contents, Glossary and Index for Series
245(C)	Section 2, Design for Terminal Effects (U)
246	Section 3, Design for Control of Flight Characteristics *(out of print)*
247	Section 4, Design for Projection
248	Section 5, Inspection Aspects of Artillery Ammunition Design
249	Section 6, Manufacture of Metallic Components of Artillery Ammunition

Automotive Series

No.	Title
355	The Automotive Assembly
356	Automotive Suspensions

Ballistic Missile Series

No.	Title
281(S-RD)	Weapon System Effectiveness (U)
282	Propulsion and Propellants

Ballistic Missile Series (continued)

No.	Title
283	Aerodynamics
284(C)	Trajectories (U)
286	Structures

Ballistics Series

No.	Title
140	Trajectories, Differential Effects, and Data for Projectiles
150	Interior Ballistics of Guns
160(S)	Elements of Terminal Ballistics, Part One, Introduction, Kill Mechanisms, and Vulnerability (U)
161(S)	Elements of Terminal Ballistics, Part Two, Collection and Analysis of Data Concerning Targets (U)
162(S-RD)	Elements of Terminal Ballistics, Part Three, Application to Missile and Space Targets (U)

Carriages and Mounts Series

No.	Title
340	Carriages and Mounts--General
341	Cradles
342	Recoil Systems
343	Top Carriages
344	Bottom Carriages
345	Equilibrators
346	Elevating Mechanisms
347	Traversing Mechanisms

Guns Series

No.	Title
250	Guns--General
252	Gun Tubes

Military Pyrotechnics Series

No.	Title
186	Part Two, Safety, Procedures and Glossary
187	Part Three, Properties of Materials Used in Pyrotechnic Compositions
189	Part Five, Bibliography

Surface-to-Air Missile Series

No.	Title
291	Part One, System Integration
292	Part Two, Weapon Control
293	Part Three, Computers
294(S)	Part Four, Missile Armament (U)
295(S)	Part Five, Countermeasures (U)
296	Part Six, Structures and Power Sources
297(S)	Part Seven, Sample Problem (U)

*Materials Series**

No.	Title
149	Rubber and Rubber-Like Materials
212	Gasket Materials (Nonmetallic)
691	Adhesives
692	Guide to Selection of Rubber O-Rings
693	Magnesium and Magnesium Alloys
694	Aluminum and Aluminum Alloys
697	Titanium and Titanium Alloys
698	Copper and Copper Alloys
699	Guide to Specifications for Flexible Rubber Products
700	Plastics
721	Corrosion and Corrosion Protection of Metals
722	Glass

*The Materials Series is being published as Military Handbooks (MIL-HDBK-) which are available to Department of Defense Agencies from the Naval Supply Depot, 5801 Tabor Avenue, Philadelphia, Pennsylvania 19120.

LOGISTICS

COMPLETE ROUND CHARTS

ARTILLERY AMMUNITION

U.S. ARMY MATERIEL COMMAND NOVEMBER 1985

CHART 1. 40-MILLIMETER AMMUNITION
(Continued)

	CARTRIDGE								PROJECTILE							
										FILLER			COMPONENTS			
LINE NO.	TYPE CLASSI-FICA-TION	MSR, AMCTCM OR OTCM NO.	MODEL DESIG-NATION	TYPE	NOMINAL WT (LB)	ASSEMBLY DWG. NO.	SPEC. NO.	MODEL OF WEAPON	PROJEC-TILE ASSEMBLY DWG. NO.	COM-POSI-TION	WT (LB)	DWG. NO.	KIND	WT (LB)	DWG. NO.	METAL PARTS ASSEMBLY DWG. NO.
27	LCC-A	05756002	M781	Practice	205 g	9322240	MIL-C-63239	40 MM Gren Lchr M79 M203	9322237	Orange Dye	----	---	---	---	---	9322237
28	STD	7517	M674	Riot Control CS	0.75	122-3-101	MIL-C-60303	40 MM Gren Lchr M79	123-3-101	CS (MIX)	0.21 (96 g)	143-14-7	1st Fire	---	143-9-3	---
29	STD LCC-A	09766018	M713	Ground Marker Red Smoke	0.49	9323251	MIL-C-63129	40 MM Gren Lchr M79 M203	9323252	Red Smoke Comp	0.165 (75 g)	9323277	---	---	---	9258731
30	STD LCC-A	09766018	M715	Ground Marker Green Smoke	0.49	9323261	MIL-C-63130	40 MM Gren Lchr M79 M203	9323262	Green Smoke Comp	0.165 (75 g)	9323274	---	---	---	9258731
31	STD LCC-A	09766018	M716	Ground Marker Yellow Smoke	0.49	9323265	MIL-C-63131	40 MM Gren Lchr M79 M203	9323260	Yellow Smoke Comp	0.165 (75 g)	9323276	---	---	---	9258731
32	STD	8367	M651	Tactical CS	10.0	122-2-6	EA-PD-196-131-835	40 MM Gren Lchr M79 M203	122-2-6	CS Pyro	0.13 (59 g)	122-2-6	---	---	---	122-2-4
33	C&T	37119	M91	TP-T	4.72	75-1-173	None	Guns M1 M2 MK1	75-14-433	--	----	---	Tracer	0.02	---	75-2-329
34	CON	11756003	M583A1	White Star Para	0.439	9243881	MIL-C-50510	40 MM Gren Lchr M79 M203	9243909	Illum	0.21 (96 g)	9244310	---	---	---	9243909
35	CON	11756003	M585	White Star Cluster	0.410	9243880	MIL-C-50509	40 MM Gren Lchr M79 M203	9243884	Illum.	0.22 (100 g)	9243901	---	---	---	92119189 9243884
36	STD	05826003	M811 3/	HE-I	5.5	12600009	MIL-C-63553	M247 DIVADS	12600052	Octol NNL	0.165 g	---	Incend	---	---	1200052
37	STD	05826003	M813 3/	TP	5.5	12600003	MIL-C-63551	M247 DIVADS	12600036	Inert	---	---	---	---	---	1200028
38	STD	05826003	M822 3/	HE	5.5	12600002	MIL-C-63556	M247 DIVADS	12600022	Octol	120 g	12600022	Tungsten Balls	---	---	12600022
39	STD	05826003	M851 3/	Dummy	5.5	12600005	MIL-C-63562	M247 DIVADS	12600005	---	---	---	---	---	---	12600005

1/Range to self-destruct
2/40mm Machinegun
3/SGT York

CHART 1. 40-MILLIMETER AMMUNITION (Continued)

BODY			FUZE			PROPELLING ASSEMBLAGE								PERFORMANCE		PACKING	
						CARTRIDGE CASE		PROPELLANT			PRIMER						
MATERIAL	MATERIAL FORM	DWG. NO.	DESIGNATION	TYPE	DWG. NO.	DESIGNATION	DWG. NO.	COMPOSITION	NOM. WT (LB)	DWG. NO.	DESIGNATION	TYPE	DWG. NO.	MAX. RANGE yd(m)	MV fps(mps)	INNER PACK DWG. NO.	OUTER PACK DWG. NO.
Plastic Alum Steel	---	9322237	---	---	---	M212	9322239	M9	340 mg	---	No. 1-1/2 Commercial	38 Cal Blank Cart.	9322238	440 (400m)	250 (75 mps)	9325893 or 9209204	9325896 or 9209205
Alum	Forged	122-3-104	---	---	---	---	---	BP	0.02 oz	122-3-101	Commercial	Remmington 68	--	--	--	122-3-128	122-3-129
Alum	Impact	9258731	M733	Pyro	9323255	M118	8844610	M9	330 mg	9276547	M42 FED 100	Perc	9235929	440 (400m)	250 (75 mps)	9209204	9209205
Alum	Impact	9258731	M733	Pyro	9323255	M118	8844610	M9	330 mg	9276547	M42 FED 100	Perc	9235929	440 (400m)	250 (75 mps)	9209204	9209205
Alum	Impact	9258731	M733	Pyro	9323255	M118	8844610	M9	330 mg	9276547	M42 FED 100	Perc	9235929	440 (400m)	250 (75 mps)	9209204	9209205
Alum	Mach	122-2-4	M551E1	PD	9219774	M118	122-2-35	M9	---	8844609	M42	Perc	8799925	440 (400m)	245	---	---
Steel	Bar	75-2-329	M69	Dummy	72-5-9	M25 M25B1	71-2-122 71-2-130	M1	0.72	75-1-173	M38A1 M38B2 MK22	Perc	8839379 8839378 328952 Navy	11000 (9900m)	2870 (947 mps)	Navy 880741	8796464
Alum	Impact	9207993	---	---	---	M195	9207988	M9	---	9207988	Fed 100 M42	Perc Perc	9235929 8799925	Burst Ht 168 Meters QE-85°	---	9209204	9209205
Alum	Impact or Bar	9207993	---	---	---	M195	9207988	M9	---	9207988	FED 100 M42	Perc Perc	9235929 8799925	Burst Ht 168 Meters QE-85°	250 (75 mps)	9209204	9209205
Alloy Steel	Bar	1200052	M761	PD	28117739	L70	12600026	1030	515 g	12600033	MK22	Perc	12600026	7 km	1030 mps	Clip 4 Rd M6 12619467	12619468
Carbon Steel	Bar	1200028	---	---	---	L70	12600026	1030	515 g	1200033	MK22	Perc	12600026	7 km	1030 mps	Clip 4 Rd M6 12619467	12619468
Alloy Steel	Bar	12600022	M766	Prox	12705006	L70	12600026	1100	515 g	12600036	MK22	Perc	---	7 km	1100 mps	Clip 4 Rd M6 12619467	12619468
Alum Alloy	Temper T651	QQ-22519	---	---	---	---	---	---	---	---	---	---	--	---	---	---	12619468

CHART 2. 57-MILLIMETER AMMUNITION

CARTRIDGE									PROJECTILE							
										FILLER			COMPONENTS			
LINE NO.	TYPE CLASSI-FICA-TION	MSR, AMCTCM OR OTCM NO.	MODEL DESIG-NATION	TYPE	NOMINAL WT (LB)	ASSEMBLY DWG NO.	SPEC NO.	MODEL OF CANNON	PROJEC-TILE ASSEMBLY DWG NO.	COM-POSI-TION	WT (LB)	DWG NO	KIND	WT (LB)	DWG NO.	METAL PARTS ASSEMBLY DWG NO.
1	LP	7875	T25E5	Cstr	5.43	9215708	MIL-C-48050	Rifle M18A1 M18	Cstr 9215709	Steel Slug	1.8	9215715	---	---	---	9215709
2	OBS	35983	M22	Dummy	12.56	72-3-93	None	Gun M1	72-3-93	---	---	---	---	---	---	---
3	CON	37119	M306A1 1/	HE	5.46	75-1-216 9215030	MIL-C-1391 MIL-C-60464	Rifle M18A1 M18	75-14-488 9215029	Comp B	0.55	75-14-488 9215029	---	---	---	75-2-359 10535913
4	CON	37119	M307A1 2/	HEAT	5.43	75-1-215	MIL-C-1387	Rifle M18A1 M18	75-14-472	Comp B 3/	0.40	75-14-472	Tetryl Booster	0.015	75-14-472 75-1-215	75-2-353
5	OBS	35983	M303	HE-T	12.88	75-1-188	PXS-1104	Gun M1	75-14-458	TNT	0.44	75-14-458	Red Tracer	0.006	---	75-2-347
6	CON	37119	M308A1 2/	Smoke	5.43	9215427	MIL-C-12825	Rifle M18A1 M18	9233510	WP	0.37	75-1-219	Burster M21	0.19 oz	9238782 9215427	75-2-496 10543043
7	CON	37119	M306A1	TP	5.4	75-1-252	MIL-C-1386	Rifle M18A1 M18	75-14-587	Inert Mat'l	0.45	75-14-587	Black Powder Pellet	0.07	75-1-252	75-2-359

1/ M306 - differs in the design of the crimping groove and in the projectile filler of east TNT

2/ M307, M308 - differ in the use of a paper-lined cartridge case, M30 and percussion primer, M46

3/ 50 — 50 pentolite alt.

CHART 2. 57-MILLIMETER AMMUNITION

			FUZE			PROPELLING ASSEMBLAGE									PERFORMANCE		PACKING	
BODY						CARTRIDGE CASE		PROPELLANT			PRIMER							
MATERIAL	MATERIAL FORM	DWG NO.	DESIGNATION	TYPE	DWG NO.	DESIGNATION	DWG NO.	COMPOSITION	NOM WT (LB)	DWG NO.	DESIGNATION	TYPE	DWG NO.	MAX RANGE yd(m)	MV fps(mps)	INNER PACK DWG NO.	OUTER PACK DWG NO.
Carbon Steel	Tube	9215712	---	---	---	M30A1B1 M30A1B2	10535911	M10	1	9215708	M60A1	Perc	8839466	775 (160m)	1200 (396mps)	9216239	9216240
Steel	---	72-3-93	---	Dummy	---	M23A2B1	72-3-93	--	---	---	---	--	---	---	---	76-1-603	76-1-1262
Steel	Forged	75-2-431 10535914	M503A1 M503 Series M503A2	PD	73-2-320 9215031	M30A1B1 M30A1B2	10535911	M10	1	75-1-216 9215030	M60A1 M60 M46	Perc	8839466 8839465	4508 (4057m)	1200 (396mps)	76-1-807	8796471
Steel	Forged	75-2-354	M90A1 M90	PI	73-2-236	M30A1B1	10535911	M10	1	75-1-215	M60A1 M60	Perc	8839466	4860 (4374m)	1200 (396mps)	76-1-808	8796691
Steel	Bar	75-2-347	M86 M85	PD	73-2-221 73-2-215	M23A2	71-2-120	FNH Powder	2.28	75-1-188	M1B1A2 M1A2 M1B2	Perc	8839474 8839453 8838167	8800 (7920m)	2720 (898mps)	76-1-942	76-1-945
Steel	Forged	75-2-364 10543046	M503 M503 Series	PD	73-2-320 9215031	M30A1B1	10535911	M10	1	75-1-219	M60A1	Perc	8839466	4508 (4057m)	1200 (396mps)	8796521	8796471
Steel	Forged	75-2-431	M503A1 M503	PD	73-2-320	M30A1B1	10535911	M10	1	75-1-252	M60A1	Perc	8839466	4508 (4057m)	1200 (396mps)	9215018	8796471

CHART 3. 60-MILLIMETER MORTAR AMMUNITION

CARTRIDGE									PROJECTILE							
										FILLER			COMPONENTS			
LINE NO.	TYPE CLASSI-FICA-TION	MSR, AMCTCM OR OTCM NO.	MODEL DESIG-NATION	TYPE	NOMINAL WT. (LB)	ASSEMBLY DWG NO.	SPEC NO.	MODEL OF MORTAR	LOADING ASSEMBLY DWG NO	COMPOSI-TION	WT (LB)	DWG NO.	KIND	WT (LB)	DWG NO.	METAL PARTS ASSEMBLY DWG NO.
1	OBS	11756003	M49A2	HE	3.07	75-1-82	MIL-S-1436	M2 M19 M224	75-14-257	Flake TNT	0.34	75-14-257	--	--	--	75-2-288
2	CON 4/	6632 6389	M49A3 (M49A2E1)	HE	3.07	9207925	PA-PD-2701	M2 M19 M224	9207926	Comp B	0.42	9207926	--	--	--	9207928 10535905
3	CON	11756003	M49A4 (M49A2E2)	HE	3.25	9220179	MIL-C-14750	M2 M19 M224	9207926	Comp B	0.42	9207926	--	--	--	9207928 10535905
4	STD	01786006	M720	HE	3.75	9275526	MIL-C-48368	M2 M19 M224	75-14-350	Comp B	0.42	9207926	--	--	--	9207928 10535905
5	STD CON CON	8346 37119 4660	M83A3 M83A2 M83A1	Illum	4.15	9207516 75-1-143	MIL-C-3972	M2 M19 M224	9207517 75-14-350	Illum	0.49	9207518	1st Fire	0.035	9207518 78-2-272	9207530 75-2-547
6	CON	4660	M302	Smoke	3.98	9205340	MIL-C-60317	M2 M19 M224	9205339	WP	0.75	9205339	B'str Proj M19	0.025	9205343	10534894
7	STD	8346	M302A1 (M302E1)	Smoke	4.10	9215575	MIL-C-60317	M2 M19 M224	9205339	WP	0.75	9205339	B'str Proj M19	0.025	9205343	10534894
8	CON	37119	M69	Tng	4.43	9222944	OAC-PD-58	M2 M19 M224	9222944	-- Invert	--	--	--	--	--	9222944
9	OBS 6/ C & T	37344 6632 6389	M50A2 M50A3	TP TP	3.05 3.15	75-1-83 9220383	MIL-S-1436 PA-PD-2904	M2 M19 M224	75-14-238 9220384	Cast Filler C Invert	0.37 0.29	75-14-238 9220384	BPF BPP	0.05 0.05	75-1-83 7549196	75-2-288 9207928
10	STD LCC-A	04836005	M888 8	HE	3.90	9354400	MIL-C-64037	M224	9207926	Comp B	0.79	9207926	--	--	--	9207920 10535905

1/ Fuze, Series, PD, M52, M53, M82 - (Fuze PD, M52 Series obsolete - AMCTC 6558).
2/ Issued separately
3/ M4 Ignition Cartridge contains a primer in its base and may be issued in lieu of M5A1 Ignition Cartridge.
4/ STD B for Marine Corps use AMCTC-6389.
5/ M717 Fuze Permanently Suspended except for Emergency Combat
6/ STD A for Marine Corps use AMCTC-6399.
7 OR M2 MOD

CHART 3. 60-MILLIMETER MORTAR AMMUNITION

BODY			FIN		FUZE			PROPELLING ASSEMBLAGE: PROPELLANT INCREMENT			PROPELLING ASSEMBLAGE: IGNITION CARTRIDGE	PROPELLING ASSEMBLAGE: PRI PRIMER		PERFORMANCE		PACKING	
MATERIAL	MATERIAL FORM	DWG NO	DESIG-NATION	DWG NO.	DESIG-NATION	TYPE	DWG NO	DESIG-NATION AND NO. USED	(GRAINS) & TYPE	DWG NO	DESIG-NATION NO. AND DWG	TYPE	DWG NO	MAX. RANGE yd (m)	MV fps (mps)	INNER PACK DWG NO.	OUTER PACK DWG NO
Steel	Forg	75-2-539	M2	9207612	1/ M525 Series	PD	8800197	M3A1 3/	0.021 M8	9205610	M5A2 9242127	M32 Perc	8880637	1978	516	7549170	8796472
PMI Steel	Cast Forg	9207926 10535906 10535924	M2	9207612	1/ M525 M525A1	PD	8800197	M3A1 3/	0.021 M8	9205610	M5A2 8880647 9242127	M32 Perc	8880637	1978	518	7549170	8796472
PMI Steel	Cast Forg	9207926 10535906 10535924	M2 & Extension	9207612 9215574	1/ M525 Series M717/5	PD PD	8800197 9220860	M181 3/	0.026 M8	9216090	M5A2 9242127	M32 Perc	8880637	1985	520	9220014	9220015
Alloy Steel	Cast Forg	9236378	M27	11751196	M734	Multi-option	11723100	M204	125.0 M10	9312698	M702 9280553	M35 Perc	9285481	3490 m	810	9252724	9317918
Steel Tubing	Forg	9207531 75-2-316	M2	9207612	M65A1	Time	9207568 73-3-177	M182 3/ M3A1 M3A1	0.021 M8	9216363 9205610	M5A2 9242127	M32 Perc	8880637	1100	434	9242065	9242066
Steel	Forg	10534895	M2	9207612	M527 Series	PD	8800461	M3A1 3/	0.021 M8	9205610	M5A2 9242127	M32 Perc	8880637	1610	439	9205613	8796473
Steel	Forg	10534895	M2 & Extension	9207612 9215574	M527B1 Series	PD	8800461	M181 4/	0.026 M8	9216090	M5A2 9242127	M32 Perc	8880637	1582	439	9215576	9215577
Iron	Cast	75-2-303	M3 7/	2/ 9222945	--	--	--	--	--	--	2/ 3/ M5A2 9242127	2 M32 Perc	8880637	235 193 m	152.5 46.4		9223900
Steel PMI	Forg Cast	75-2-288 9207926	M2 M2 & Extension	75-2-285 9215574	1/ M525 Series	PD PD	75-1-161 8800197	M3A1 3/ M181 3	0.021 M8 0.026 M8	9205610 9216090	M5A2 9242127	M32 Perc	8880637	1978 1963	518 520	7549170 9220014	8796472 9220015
Alloy Steel	Cast Forg	9236378-2	M27	11751196	M935	PD	9255254	M204	125.0 M10	9312695	M702 9280553	M35 Perc	9285481	--	--	9260110	9280108 9280109

- Ctg 60mm: HE, M888 not to be fired in Mortars M2 or M19.

NOTE: 60mm Sabot Training is listed on page 18.

CHART 4. 75-MILLIMETER AMMUNITION

CARTRIDGE									PROJECTILE							
										FILLER			COMPONENTS			
LINE NO.	TYPE-CLASSI-FICA-TION	MSR, AMCTCM OR OTCM NO.	MODEL DESIG-NATION	TYPE	NOMINAL WT (LB)	ASSEMBLY DWG NO.	SPEC NO.	MODEL OF CANNON	PROJEC-TILE ASSEMBLY DWG NO.	COM-POSI-TION	WT (LB)	DWG NO.	KIND	WT (LB)	DWG NO.	METAL PARTS ASSEMBLY DWG NO.
1	CON	34566	M61A1	APC-T	19.91	75-1-103	MIL-R-20520	Gun M3	75-14-268	Exp D	0.144	75-14-268	Tracer M5A2B1	0.10	8796866	75-2-291
2	OBS	31599	M72	AP-T	18.84	75-1-127	PXS-907	Gun M3 M6 M17	75-14-299	–	–	–	Tracer	0.10	75-14-299	75-2-305
3	OBS	36608	M338A1 M338A2	AP-T	18.26	75-1-312	PA-PD-57	Gun M3 M6	75-2-494	–	–	–	Tracer M5A2B1	0.10	8796866	75-2-494
4	OBS	37119	M2A2	Dummy	19.2	72-3-59	–	How M1A1 M1A1C M3	72-3-59	–	–	–	–	–	–	–
5	OBS	11756003	M7	Dummy	20.38	72-3-65	–	Gun M3	72-3-65	–	–	–	–	–	–	–
6	OBS	11756003	M16	Dummy	18.75	72-3-82	–	Gun M3 How M1A1	72-3-82	–	–	–	–	–	–	–
7	OBS	37119	M19B1 M19	Dummy	18.24	72-3-89		How M1A1	72-3-89	–	–	–	–	–	–	–
8	OBS	11756003	M48	HE	19.48	75-1-78	MIL-S-20532	Gun M3 M6 M17	75-14-198	TNT	1.49	75-14-198	–	–	–	75-2-269
9	OBS	11756003	M48	HE	18.75 18.24	75-1-79	MIL-S-20532	Gun M3 M6 M17	75-14-198	TNT 50-50 Amatol	1.49	75-14-198	–	–	–	75-2-269
10	OBS	11756003	M48	HE	18.18	75-1-80	MIL-S-20532	Gun M3 M6 M17	75-14-198	TNT	1.49	75-14-198	–	–	–	75-2-269
11	CON	6418	M48	HE	16.57	75-1-247	MIL-S-20532	How M1A1	75-14-445	TNT	1.04	75-14-445	Suppl Chg TNT	0.365	8797090	75-2-269

CHART 4. 75-MILLIMETER AMMUNITION

BODY			FUZE			PROPELLING ASSEMBLAGE								PERFORMANCE		PACKING	
						CARTRIDGE CASE		PROPELLANT			PRIMER						
MATERIAL	MATERIAL FORM	DWG NO.	DESIGNATION	TYPE	DWG NO.	DESIGNATION	DWG NO.	COMPOSITION	NOM WT (LB)	DWG NO.	DESIGNATION	TYPE	DWG NO.	MAX RANGE YD (m)	MV FPS (mps)	INNER PACK DWG NO.	OUTER PACK DWG NO.
Steel	Bar or Forged	75-2-328	M66A2	BD	73-2-178	M18 M18B1	71-2-71 71-2-150	M1	2.0	75-1-103	M31B2	Perc	8839469	1,230 (1,124 m)	2,030 (618 mps)	76-1-1124	76-1-522
Steel	Bar	75-2-305	–	–	–	M18	71-2-71	M1	1.9	75-1-127	M31A2	Perc	8839467	10,600 (9,692 m)	2,030 (618 mps)	76-1-376	76-1-376
Steel	Bar	75-2-495	–	–	–	M18 M18B1	71-2-71 71-2-150	M17	2.10	75-1-312	M31A2	Perc	8839467	12,255 (11,205 m)	2,120 (646 mps)	76-1-1398	76-1-1399
Bronze	Cast	72-3-69	M1907M	Inert.	73-3-114	–	–	–	–	–	–	–	–	–	–	76-1-266	76-1-522
Bronze	Cast	72-3-66	M1907M	Inert	73-3-114	–	–	–	–	–	–	–	–	–	–	76-1-1259	76-1-1125
Bronze	Cast	72-3-63	M59	Dummy	72-5-5	–	–	–	–	–	–	–	–	–	–	76-1-603	76-1-522
Iron & Bronze	Cast	72-3-90	M59	Dummy	72-5-5	–	–	–	–	–	–	–	–	–	–	76-1-266	76-1-522
Steel	Forged	75-20-77	M51A5 M51A4	PD	8796862 73-2-145	M18 M18B1	71-2-71 71-2-150	M1	1.93 S Chg	75-1-78	M31B2	Perc	8839469	14,000 (12,801 m)	1,950 (594 mps)	76-1-1120	76-1-1229
Steel	Forged	75-20-77	M51A5 M51A4 4/	PD PDCP	8796862 73-2-214	M5A1 M5A1B1	71-2-91	M1	1.15 N Chg	75-1-79	M1 M1A1 M1A2 M1B1A2 M64	Perc	74-2-63 8839474 8839461 74-2-63	11,285 (10,319 m)	1,250 (381 mps)	76-1-1120	76-1-1229
Steel	Forged	75-20-77	M51A5 4/	PD	8796862	M18 M18B1	71-2-71 71-2-150	M1	0.59 R Chg	75-1-80	M22A3	Perc	8839458	6,990 (6,391 m)	950 (289 mps)	76-1-1120	76-1-1229
Steel	Forged	75-20-77	M513	Prox 1/	1310500	M5A1	71-2-91	M1	1.06	8865404	M1B1A2	Perc	8839474	9,620 (7,916 m)	1,250 (381 mps)	76-1-1124	76-1-1231

CHART 4. 75-MILLIMETER AMMUNITION (Continued)

CARTRIDGE									PROJECTILE							
										FILLER			COMPONENTS			
LINE NO.	TYPE-CLASSI-FICA-TION	MSR, AMCTCM OR OTCM NO.	MODEL DESIG-NATION	TYPE	NOMINAL WT (LB)	ASSEMBLY DWG NO.	SPEC NO.	MODEL OF CANNON	PROJEC-TILE ASSEMBLY DWG NO.	COM-POSI-TION	WT (LB)	DWG NO.	KIND	WT (LB)	DWG NO.	METAL PARTS ASSEMBLY DWG NO.
12	CON	6418	M48	HE	18.30	75-1-59	MIL-S-20532	How M1A1	75-14-198	TNT 50-50 Amatol	1.04 1.36	75-14-198	–	–	–	75-2-269
13	CON	6418	M46	HE	18.30	75-1-183	MIL-S-20532	How M1A1	75-14-445	TNT	1.49	75-14-445	Suppl Chg	0.365	8797090	75-2-269
14	CON	6418	M48	HE	18.22	75-1-206	MIL-S-20532	How M1A1 M3	75-14-445	TNT	1.49	75-14-445	Suppl Chg	0.365	8797090	75-2-269
15	OBS	11756003	M309A1 M309	HE	22.37	75-1-221	MIL-C-1391	Rifle M20	75-14-498 8826754	TNT	1.49	75-14-498	–	–	–	75-2-365
16	OBS	37119	M66	HEAT-T	15.66	75-1-141	MIL-S-10363	How M1A1 M3	75-14-499	Comp B	1.0	75-14-499	–	–	–	75-2-314
17	OBS	11756003	M310A1 M310 5/	HEAT-T	21.06	75-1-222	MIL-C-1388	Rifle M20	75-14-499	Comp B Pentolite	1.0	75-14-499	Tracer M5	0.10	8853694	75-2-366
18	OBS	11756003	M349	HEP-T	16.70	75-1-326	MIL-C-12838	Rifle M20	75-14-682	Comp A-3	2.55	75-1-682	Tracer M5	0.10	8853694	75-2-535
19	OBS	37344	M64	Smoke	19.00	75-1-114	MIL-S-3139	How M1A1 M1A1C M3	75-14-276	WP	1.34	75-14-276	Burster M6	0.11	73-1-224	75-2-294
20	OBS	11756003	M311A1 M311	Smoke	23.20	75-1-225	MIL-C-12825	Rifle M20	75-14-503	WP -	1.35	75-14-503	Burster Initiator Chg	0.07 0.11	73-1-224 73-1-184	75-2-371
21	OBS	11756003	M309A1 M309	TP	22.37	75-1-251	MIL-C-1386	Rifle M20	75-14-586	Inert Mat'l	1.27	75-41-586	BP Pellets	0.22	75-1-251	75-2-365

1/ May be issued with closing plug and with or without supplementary charge (to be removed if proximity fuze is used).
2/ 2800 yards with TNT; 2825 yards with Comp B.
3/ Cartridge 75MM: TP W/F PD Obsolete.
4/ Fuzes, PD, M51A4 and M51A5 restricted to Combat Emergency Use Only - TB 9-1300-385 - except for 76MM and 90MM Guns.
5/ Cartridge M310 Fuze with M62A1 obsolete.

CHART 4. 75-MILLIMETER AMMUNITION (Continued)

BODY			FUZE			PROPELLING ASSEMBLAGE								PERFORMANCE		PACKING	
						CARTRIDGE CASE		PROPELLANT			PRIMER						
MATERIAL	MATERIAL FORM	DWG NO.	DESIGNATION	TYPE	DWG NO.	DESIGNATION	DWG NO.	COMPOSITION	NOM WT (LB)	DWG NO.	DESIGNATION	TYPE	DWG NO.	MAX RANGE YD (m)	MV fps (mps)	INNER PACK DWG NO.	OUTER PACK DWG NO.
Steel	Forged	75-2-77	M557	PD	8863535	M5A1	71-2-91	M1	1.06	8865404	M1B1A2 M1	Perc	8839474	9,620 (7,916 m)	1,250 (381 mps)	76-1-1124	76-1-662
Steel	Forged	75-20-77	M557	PD	8863535	M5A1	71-2-91	M1	1.06	8865404	M1B1A2 M1	Perc	8839474	9,620 (7,916 m)	1,250 (381 mps)	76-1-1124	76-1-662
Steel	Forged	75-20-77	M520 Series	MTSQ	8594044	M5A1	71-2-91	M1	0.95	8865404	M64	Perc	8839461 74-2-63	9,620 (7,916 m)	1,250 (381 mps)	76-1-1124	76-1-1231
Steel	Forged	75-2-551	M557	PD	8863535	M31A1 M31	7548024	M10	3.30	75-1-221	M47 M47B2	Perc	8839455 8839460	6,960 (6,364 m)	990 (271 mps)	76-1-1123	76-1-835
Steel	Forged	75-20-93	M91A2	BD	8837306	M5A1	71-2-91	M2	0.41	75-1-141	M23A2 M1	Perc	8831161 74-2-63	6,540 (5,980 m)	1,000 (304 mps)	76-1-603	P80613
Steel	Forged	75-20-93	M91A1 M62A1	BD BD	8837306 8886414	M31A1 M31	7548024	M10	3.19	75-1-222	M47 M47B2	Perc	8839455 8839460	7,300 (6,675 m)	1,000 (304 mps)	76-1-10830	76-1-835
Steel	Forged	75-2-336	M91A1	BD	8837306	M31A1 M31	7548024	M10	3.36	75-1-328	M47B2 M47	Perc	8839460 8839455	7,180 (6,565 m)	1,400 (427 mps)	76-1-1411	76-1-1410
Steel	Forged	75-2-294	M48A3	PD	8798219	M5A1	71-2-91	M1	1.06	71-9-126	M64 M1	Perc	8839461 74-2-63	9,620 (7,916 m)	1,250 (381 mps)	76-1-893	76-1-662
Steel	Forged	75-2-371	M48A3	PD	8798219	M31A1 M31	7548024	M10	3.42	75-1-225	M47B2 M47	Perc	8839460 8839455	6,960 (6,364 m)	990 (271 mps)	76-1-883	76-1-835
Steel	Forged	75-2-551	M73	Dummy	8796863	M31	7548024	M10	3.30	75-1-221	M47B2 M47	Perc	8839460 8839455	6,960 (6,364 m)	990 (271 mps)	76-1-828	76-1-835

CHART 5. 75-MILLIMETER AMMUNITION

	CARTRIDGE								PROJECTILE							
										FILLER			COMPONENTS			
	TYPE CLASSI-FICA-TION	MSR, AMCTCM OR OTCM NO.	MODEL DESIG-NATION	TYPE	NOMINAL WT (LB)	ASSEMBLY DWG NO.	SPEC NO.	MODEL OF CANNON	PROJEC-TILE ASSEMBLY DWG NO.	COM-POSI-TION	WT (LB)	DWG NO.	KIND	WT (LB)	DWG NO.	METAL PARTS ASSEMBLY DWG NO.
1	OBS	11756003	M339	AP-T	27.32	8886612	MIL-C-46523	Gun M32 M48	8886612	–	–	–	Tracer M13	0.10	8796866	10520209
2	OBS	36767	M62A1	APC-T	25.15	75-1-150	MIL-C-20520	Gun M1A1C M1A2	75-14-269	Explosive D	0.144	75-14-269	–	–	–	75-2-292
3	OBS	11756003	M363	Cstr	27.18	9204458	MIL-C-60310	Gun M32 M48	10534422	Steel Balls	9.00	10534425	–	–	–	10534423
4	STD OBS	36841 36767	M20 M20B1	Dummy	24.8	72-3-87		Gun M1A2 M1A2	72-3-87	–	–	–	–	–	–	72-3-87
5	OBS STD	11756003 6267	M352 M352A1	HE	25.52	75-1-293	MIL-C-13140	Gun M32 M48	75-14-635	Comp B	1.46	75-14-635	–	–	–	75-2-434
6	OBS	36767	M42A1	HE	22.11	75-1-149	MIL-S-20532	Gun M1A1C M1A2	75-14-170	Comp B	0.90	75-14-170	Booster M21A4	0.048	8798123	75-18-33
7	OBS	11756003	M496	HEAT-T	25.83	8848863	MIL-C-46503	Gun M32 M48	8848862	Comp B	1.10	8848862	Tracer M13	0.036	8860550	8597471
8	OBS STD	11756003 36841	M331A1 M331A2	HVAP-DS-T	20.7	75-1-308	MIL-C-12579	Gun M32 M48	75-14-648	–	–	–	Tracer M5 M5A3	0.10	75-17-13	75-2-475
9	OBS	36767	M93A1	HVAP-T	18.39	75-1-220	MIL-C-20608	Gun M1A1C M1A2	75-2-361	–	–	–	Tracer M5A1B1	0.10	8796866	75-2-361
10	OBS	36767	M315A1	HVTP-T	18.26	75-1-249	MIL-C-20608	Gun M1A1C M1A2	75-2-390	–	–	–	Tracer M5A1B1	0.10	8796866	75-2-390
11	CON	6267	M319	HVAP-T	19.04	75-1-295	MIL-C-20608	Gun M32 M48	75-2-440	–	–	–	Tracer M5A1B1 M5A1	0.10	8796866	75-2-440
12	OBS	36767	M312B1 M312B2	Smoke	22.66 1/ 22.31 2/	75-1-227 1/ 75-1-253 2/	MIL-S-3139	Gun M1A2 M1A1C	75-14-607 1/ 75-14-500 2/	WP	0.78 1/ 0.73 2/	75-14-607 1/ 75-14-500 2/	Burster Chg. M23	0.16	73-1-215	75-2-405 1/ 75-2-419 2/
13	OBS	11756003	M361	Smoke	25.82	P85133	MIL-C-45115	Gun M32 M48	P85134	WP	1.38	P85133	Burster Projec-tile M39		P85171	P85134
14	OBS	11756003	M340A1 M340	TP-T	27.32	8857345	MIL-C-45443	Gun M32 M48	8857345	–	–	–	Tracer M5A2B1 (M340) M13 (M340A1)	0.10	8796866	10520215

1/ Applicable to M312B1
2/ Applicable to M312B2
3/ Cast Bronze, - applicable to M20
4/ Malleable Iron - applicable to M20B1
5/ Tungsten carbide steel, and Aluminum.

CHART 5. 75-MILLIMETER AMMUNITION

BODY			FUZE			PROPELLING ASSEMBLAGE								PERFORMANCE		PACKING	
						CARTRIDGE CASE		PROPELLANT			PRIMER						
MATERIAL	MATERIAL FORM	DWG NO.	DESIGNATION	TYPE	DWG NO	DESIGNATION	DWG NO.	COMPOSITION	NOM WT (LB)	DWG NO.	DESIGNATION	TYPE	DWG NO.	MAX RANGE (yd/m)	MV (fps/mps)	INNER PACK DWG NO.	OUTER PACK DWG NO.
Steel	Bar	10520210	–	–	–	M83B1 (steel) M88 (brass)	7548079 7548021	M30	5.60	8886612	M58	Perc 400 grains B Powder	8838153	16,419 (15,013 m)	3,200 (975 mps)	7548613	7548614
Steel	Bar	75-2-292	M66A1	BD	73-2-178	M26	71-2-123	M6	3.75	75-1-150	M40A1	Perc	8839471	17,000 (15,545 m)	2,600 (792 mps)	76-1603	76-1-652
Steel	Bar	10534430	–	–	–	M88B1 M88	7548079	M6	5.0	9204458	M62	Perc	8839454	1930 (1,755 m)	2,400 (731 mps)	9204459	9204460
3/ 4/	3/ 4/	72-3-88	M59	Dummy	72-5-5	–	–	–	–	–	–	–	–	–	–	76-1-603	76-1-652
Steel	Forged	75-2-435	M51A5	PD/ MTSQ	8796862	M88 (brass) M88B1 (steel)	7548021 7548079	M6	3.64	75-1-293	M68 M58	Perc	8796867 8838153	16,010 (14,639 m)	2,400 (731 mps)	8863694	8863695
Steel	Forged	75-20-71	M51A5	PD	8796862	M26B1 M26	71-2-201 71-2-123	M6	3.75	75-1-149	M40A1	Perc	8839471	14,600 (13,350 m)	2,700 (823 mps)	76-1-1127	76-1-1244
Steel	Bar	5597471	M509A1	PI, BD	8799735	M171A1	8595555	M6	5.06	8848863	M81	Perc	8848625	9,360 (7,644 m)	3,550 (1,082 mps)	8837842	8837841
5/	Bar	75-2-475	–	–	–	M88B1 M88	7548079 7548021	M17	5.57	75-1-308	M55	Perc	8838153	24,127 (22,062 m)	4,125 (1,257 mps)	76-1-1379	76-1-1380
Alum Alloy	Cast	75-2-361	–	–	–	M26B1 M26	71-2-201 71-2-123	M17	3.90	75-1-220	M28A2	Perc	8838129	13,000 (11,887 m)	3,400 (1,036 mps)	76-1-1101	76-1-783
Steel	Forged	75-2-391	–	–	–	M26B1 M26	71-2-201 71-2-123	M2	3.90	75-1-249	M28A2 M28B2	Perc	8838129 8838130	13,000 (11,887 m)	3,400 (1,036 mps)	76-1-1101	76-1-783
Alum Alloy	Forged	–	–	–	–	M88B1 M88	7548079 7548021	M6	5.03	75-1-295	M62 M58	Perc	8839454 8838153	11,038 (10,093 m)	4,135 (1,260 mps)	76-1-1318	76-1-1319
Steel	Forged	75-2-413 1/ 75-2-419 2/	M57 1/ M48 2/	PD PD	73-2-137 1/ 8798219 2/	M26	71-2-123	M6	3.75	75-1-227 1/ 75-1-253 2/	M40A1 1/ M28A2 2/ M28B2 2/	Perc	8839471 1/ 8838129 2/ 8838130 2/	14,360 (13,130 m)	2,700 (823 mps)	76-1-1127	76-1-1244
Steel	Forged	P85134	M521 (M361A1) M48A3 (M361)	PD	7549112	M88B1 M88	7548079 7548021	M8	3.64	P85133	M68 M58	Perc	8796867 8838153	16,296 (14,901 m)	2,400 (731 mps)	8863694	8863695
Steel	Bar	10520217	–	–	–	M88B1 M88	7548079 7548021	M30	5.60	8857345	M58	Perc	8838153	16,419 (15,013 m)	3,200 (975 mps)	7548613	7548614

CHART 6. 81-MILLIMETER MORTAR AMMUNITION

	CARTRIDGE								PROJECTILE							
										FILLER			COMPONENTS			
	TYPE CLASSI-FICA-	MSR, AMCTCM OR OTCM NO.	MODEL DESIG-NATION	TYPE	NOMINAL WT (LB)	ASSEMBLY DWG NO.	SPEC NO.	MODEL OF MORTAR	LOADING ASSEMBLY DWG NO.	COM-POSI-TION	WT (LB)	DWG NO.	KIND	WT (LB)	DWG NO.	METAL PARTS ASSEMBLY DWG NO.
1	OBS	36841 11756003	M43A1B1 M43A1	HE	7.15	9218433	MIL-S-1436	M1 M29A1 M29	9218434	Comp B	1.29	9218434	--	--	--	75-2-261
2	STD	37291	M362	HE	9.42	7549034	MIL-C-45448	M1 M29A1 M29	7549035	Comp B	2.10	7548665	--	--	--	7549015
3	CON	11756003	M362	HE	8.62	7549013	MIL-C-45448	M1 M29A1 M29	7549012	Comp B	2.10	7549012	--	--	--	7549015
4	STD	1720	M362A1	HE	9.42	8838144	MIL-C-45448	M1 M29A1 M29	8839444	Comp B	2.10	8839444	--	--	--	8596986
5	STD	1720	M362A1	HE	8.62	8839445	MIL-C-45448	M1 M29A1 M29	8839444	Comp B	2.10	8839444	--	--	--	8596986
6	CON	11756003	M374	HE	9.34	9225283 8881026	MIL-C-46995	M1 M29A1 M29	8881025	Comp B	2.10	8881025	--	--	--	10543025
7	STD	7379	M374A1	HE	9.15	9251986 9251984	MIL-C-46995	M1 M29A1 M29	8881025	Comp B	2.10	8881025	--	--	--	10543025
8	STD	03756029	M374A2 5/	HE	9.34	9251986 9240950	MIL-C-46995	M1 M29A1 M29	8881025	Comp B	2.10	8881025	--	--	--	10543025
9	STD	05756028	M374A3	HE	9.50	9241291	MIL-C-48171	M1 M29A1 M29	8881025	Comp B	2.10	8881025	--	--	--	10543025
10	CON	11756003	M301A2 M301A1	Illum-inating	10.71	8865055	MIL-C-46919	M1 M29A1 M29	8865054	Illum	1.37	8865059	First Fire Chg	0.05	8865059	10523459

CHART 6. 81-MILLIMETER MORTAR AMMUNITION

BODY			FIN		FUZE			PROPELLING ASSEMBLAGE: PROPELLANT INCREMENT			PROPELLING ASSEMBLAGE: IGNITION CARTRIDGE	PROPELLING ASSEMBLAGE: PRIMER		PERFORMANCE		PACKING	
MATERIAL	MATERIAL FORM	DWG NO.	DESIGNATION	DWG NO.	DESIGNATION	TYPE	DWG NO.	DESIGNATION AND NO. USED 17	NOM WT GRAINS	DWG NO.	DESIGNATION AND DWG NO.	DESIGNATION AND TYPE	DWG NO.	MAX RANGE (YD) yd (m)	MV fps (mps)	INNER PACK DWG NO.	OUTER PACK DWG NO.
Steel	Forg	75-2-540	M3	75-2-262	1/ M525 Series M716/	PD PD	8800197 9220859	M1A1 6/	700	9219089	M8 8865089 M6 8865062	M34 Perc	8865053	4050	834	8858643	8858642
Steel	Bar Forg (Alt)	7549020 7549021	M141	7549030	3/ M524A5	PD	9205729	M5 8/	1304	8839494	M66 8837347	M71A2 Perc	7549173	3987 9/ 2925	773 9/ 616	7549031	9230176
Steel	Bar Forg (Alt)	7549020 7549021	M141	7549030	4/ M524A6 M567 M532	 PD PD VT	 9205729 9246242 11001028	M5 8/	1304	8839494	M66 8837347	M71A2 Perc	7549173	3987 9/ 2925	773 9/ 616	7549031	9230176
7/	7/ Cast	8596989	M141	7549030	3/ M524A5	 PD	 9205729	M5 8/	1304	8839494	M66 8837347	M71A2 Perc	7549173	3987 9/ 2925	773 9/ 616	7549031	9230176
7/	7 Cast	8596989	M141	7549030	4/ M524A6 M567 M532	 PD PD VT	 9205729 9246242 11001028	M5 8/	1304	8839494	M66 8837347	M71A1 Perc	7549173	3987 9/ 2925	773 9/ 616	7549031	9230176
12/	Cast PM1 Forg Steel	10543027 10543030 10543033	10/11/ M149 M170	10/11/ 10520200 10551892	9/W/O Fuze M524 Series M524A6 M526 Series M567 M532 M716/18	 PD PD PD PD PD PRX	 9220859 9205729 9205729 8800254 9246242 11001028	16/ M90(A&B) 9/ (1A) (8B)	1528	8881021 "A" Chg. 8881023 "B" Chg.	11/12/ M66 M66A1 8837347 9233373 M285 9240960	M71A2 Perc	7549173	4932 9/	856 9/	8864657 9230175	8864663 9230176
12/	Cast Forg Bar	10543025 10543027 10543030 10543033	M149	10520200	9/W/O Fuze M524A6 M567 M522	 PD PD PRX	 9205729 9246242 11001028	17/ M90A1 9/ (1 "A") (8 "B")	1528	9233369 "A" Chg. 9233371 "B" Chg.	M66A1 9233373	M71A2 Perc	7549173	5003 9/ 3242	866 9/ 650	9230175	9230176
12/	Cast PM1 Forg Steel	10543027 10543030 10543033	M170	10551892	9/W/O Fuze M524 Series M567 M526 Series M532	 PD PD PD PD PRX	 9205729 9246242 8800254 9220859 11001028	17/ M90 9 (A&B) (1 "A") (8 "B")	1528	9233369 "A" Chg. 9233371 "B" Chg.	M285 9240960	M71A2 Perc	7549173	4932 9/	856 9/	9230175	9230176
Steel	Alloy	70543027	M24	11726889	M524A6 M567	PD PD	9205729 9246242	M205	1568	9280588	M299 9293422 M6	M35 Perc M34	8840536	5333 13/	875	9287603 9241848	9287601 9241849
Steel	Tube	10523457	M4A1 2/	10523464	M84	Time	9205598	M2A1 4/	820	8865214	8865062	Perc	8865053	3000 2350	595	7548646	7548649

CHART 6. 81-MILLIMETER MORTAR AMMUNITION (Continued)

	CARTRIDGE								PROJECTILE							
										FILLER			COMPONENTS			
	TYPE CLASSI-FICA-	MSR, AMCTCM OR OTCM NO.	MODEL DESIG-NATION	TYPE	NOMINAL WT (LB)	ASSEMBLY DWG NO.	SPEC NO.	MODEL OF MORTAR	LOADING ASSEMBLY DWG NO.	COM-POSI-TION	WT (LB)	DWG NO.	KIND	WT (LB)	DWG NO.	METAL PARTS ASSEMBLY DWG NO.
11	STD	6390	M301A3	Illum-inating	10.1	9220705	MIL-C-14909	M1 M29A1 M29	8865054	Illum	1.37	886509 8865059	First Fire Chg	0.05	8865059	9232481
12	STD	7321	M375	Smoke	9.14	8885264	MIL-C-60028	M1 M29A1 M29	8885263	WP	1.75	8885263	Chg B'ster M47	0.025	8846600	10522511
13	STD	7321	M375A1	Smoke	9.34	9251985	MIL-C-60028	M1 M29A1 M29	885263 885263	WP	1.60	8885263	Chg B'ster M47	0.025	8846600	10522511
14	STD	7321	M375A2	Smoke	9.34	9240953	MIL-C-60028	M1 M29A1 M29	8885263	WP	1.60	8885263	Chg B'ster M47	0.025	8846600	10522511
15	STD	03756028	M375A3	Smoke	9.10	9294735	MIL-C-48394	M1 M29A1 M29	8885263	WP	1.60	8885263	Chg B'ster M47	0.025	8846600	10522511
16	OBS	37196	M57A1 M57	Smoke	12.03	75-1-94	MIL-S-1436	M1 M29	75-14-255	FS	4.59	75-14-255	Chg B'ster M1	0.08	73-1-170	75-2-284
17	CON	11756003	M57A1 M57	Smoke	11.38	75-1-93	MIL-S-1436	M1 M29A1 M29	75-14-255	WP	4.06	75-14-255	Chg B'ster M1	0.08	73-1-170	75-2-284
18	STD	36841	M68	Tng	10.79	75-2-302	--	M1 M29A1 M29	--	--	-- Inert	--	--	--	--	75-2-302
19	STD	37767	M445	Tng	9.34	P87815	--	M1 M29A1 M29	P87815	Steel Slugs	2.19	P112974	Cart. Smoke 410 M152	--	P112999	7549015
20	CON	6267	M43A1	TP	7.16	75-1-89	MIL-S-1436	M1 M29A1 M29	75-14-212	Inert Mat'l	1.19	75-14-212	Spot Chg BPP	0.05	75-1-89	75-2-261
21	STD	06856008	M821	HE	8.96	9354443	GD/Prod Spec/002	M252	GD/30/ 201248 21/	RDX TNT	1.6	GD/30/ 201248 GF 21/	--	--	--	GD/30/ 200203 GE 21
22	STD	06856008	M889	HE	8.96	9354444	GD/Prod Spec/002	M252	GD/30/ 201248 21	RDX TNT	1.6	GD/30/ 201248 GF 21	--	--	--	GD/30 200203 GE 21

1/ Fuze Series, PD, M52, M53, M82 - (Fuze PD, M52 Series Obsolete - AMCTC 6558).
2/ M4A1 f/M56A1, M4f/M56.
3/ Fuze Series, PD M519. Obsolete by MSR 11756003.
4/ Assembled w/Nose Plug, Dwg. 7549009 Preferred Fuzes, PD, M524A6, M567, Prox M532.
5/ CTG M374A2 w/fuze M524A5 - CON MSR 11756003.
6/ Issued separately.
7/ Pearlitic Malleable Iron.
8/ Charge 5 for M1 Mortar.
9/ Assembled w/Nose Plug Dwg 7549076 (Alt 7549009).
10/ M149 Fin Assy must use M66A1 Ign. Cart No. 9233373 only (Yellow & Red).

CHART 6. 81-MILLIMETER MORTAR AMMUNITION (Continued)

BODY			FIN		FUZE			PROPELLING ASSEMBLAGE						PERFORMANCE		PACKING	
								PROPELLANT INCREMENT			IGNITION CARTRIDGE	PRIMER					
MATERIAL	MATERIAL FORM	DWG NO.	DESIGNATION	DWG NO.	DESIGNATION	TYPE	DWG NO.	DESIGNATION AND NO. USED 17/	NOM WT GRAINS	DWG NO.	DESIGNATION AND DWG NO.	DESIGNATION AND TYPE	DWG NO.	MAX RANGE (YD) yd (m)	MV (FPS) fps (mps)	INNER PACK DWG NO.	OUTER PACK DWG NO.
Steel	Tube	3232481 9232484	M158	9221071	M84A1	Time	9232794	M185 9/	1640	9220708	M66A1 9233373	M71A1 Perc	7549173	13/ 4265	760	9241848	9241849
14/	14/ Cast Forg Bar	10535862 10535864 10535865	10/11/ M149 M170	10520200 10551892	3/ M524A6 Ser	PD	9205729	15/ M90 9/ (1 "A") (8 "B")	1528	8881021 "A" Chg. 8881023 "B" Chg.	10/11/ M66 8837347 M66A1 9233373 8837347 M285 9240960	M71A1 M71A2	7549173	5003 8/ 3242	866 9/ 650	9230175	9230176
14/	14/ Cast Forg Bar	10535862 10535864 10535865	M149 10/	10520200	3/ M524A5 M524A6 M716/19	PD PD PD	9205729 9205729 9220859	16/ M90A1 9/ (1 "A") (8 "B")	1528	9233369 "A" Chg. 9233371 "B" Chg.	M66A1 9233373	M71A2 Perc	7549173	5003 8/ 3242	866 8/ 650	9230175	9230176
14/	Bar Forg Cast	10535862 10535864 10535865	M170	10551892	4/ M524A6 M567 M532	PD PD VT	9205729 9246242 11001028	16/ M90A1 9/ (1 "A") (8 "B")	1528	9233369 "A" Chg. 9233371 "B" Chg.	M285 9240960	M71A2 Perc	7549173	5003 8/ 3242	866 8/ 650	9230175	9230176
Steel	Forg	10543027	M24	11726889	M567 M524A6	PD PD	9246242 9205729	M205	1568	9280588	M299 9293422	M35 Perc	8840536	5333	879	9287603	9287601
Steel	Tube	75-2-284	M4A1	10523464	1/ M525 Ser	PD	8800197	M2A1 4/	820	8865214	M6 8865062	M34 Perc	8865053	2372	548	7548994	7548995
Steel	Tube	75-2-284	M4A1 M4	10523464	M525 Ser	PD	8800197	M2A1 4/	820	8865214	M6 8865062	M34 Perc	8865053	2872	2169m	7548994	7548995
Iron	Cast	75-2-302	M6 13/	75-2-396	--	--	--	--	--	--	6/ M3 75-19-76 M6 8865062 w/primer	6/ M34 Perc	8865053	310 284m	-- 173	--	76-1-338
Steel	Bar	7549020 7549021	M151	P86985	M531	Tng	P98412	--	--	--	M100	--	--	190	--	--	--
Steel	Forg	75-2-540	M3	75-2-262	1/ M525 Ser	PD	8800197	M1A1 6/	700	71-12-15	M8 8865089	M34 Perc	8865053	3300	705	8865089	8865063
20/	Cast	GD/030/ 200251 21/	--	PI/ 16591	M734	Multi Option	11723100	M223	480	GD/030/ 201062 21/	L33A1 GD/030/ 200777 21/	N/A	N/A	5700M	--	GD/030/ 100954 21/	GD/030/ 100838 21/
20/	Cast	GD/030/ 200251 21/	--	PI/ 16591	M935	PD	9255255	M223	480	GD/030/ 201062 21/	L33A1 GD/030/ 200777 21/	N/A	N/A	5700M	--	GD/030/ 100954 21/	GD/030/ 100838 21/

11/ M170 Fin Assy must use M285 Ign Cart No. 9240960 only (Yellow & Green)
12/ Material may be Pearlite Malleable Iron, Steel Alloy, Bar, Steel Plate, Steel Tube or Non Resulphurized Steel Bar.
13/ To Maximum Illuminated Range.

14/ Material may be Non-Resulphurized Steel Bar Low Carbon Bar Pearlitic Malleable.
15/ M90 Cloth Propellant Bag.
16/ M90A1 Celcon Silk Propellant Bag.
17/ No more than 5 propellant increments may be used w/M1 Mortar.
18/ Fin Assembly M6 Cont by 11756003.
19/ Fuzes P.D. M716 Permanently Suspended except for Emergency Combat.
20/ Spheroidal Graphite.
21/ British Army Drawings.

Note: 81MM Sabot M1 is listed Chart 18.

CHART 7. 90-MILLIMETER AMMUNITION

CARTRIDGE									PROJECTILE								
										FILLER			COMPONENTS				
LINE NO.	TYPE CLASSI-FICA-TION	MSR, AMCTCM OR OTCM NO.	MODEL DESIG-NATION	TYPE	NOMINAL WT (LB)	ASSEMBLY DWG NO.	SPEC NO.	MODEL OF CANNON	PROJEC-TILE ASSEMBLY DWG NO.	COM-POSI-TION	WT (LB)	DWG NO.	KIND	WT (LB)	DWG NO.	MODEL PARTS ASSEMBLY DWG NO.	
1	OBS	11756003	M77	AP-T	42.04	75-1-136		Guns M1, M2, Ser. M36 M41 M54	75-14-334	–	–	–	Tracer M3	0.01	75-14-330	75-18-44	
2	STD STD	37119 36841	M318 M318A1 M318A1E1	AP-T	43.98 43.91	75-1-358 9207966	MK-C-45110	Guns M36, M41, M54	10522523	–	–	–	Tracer M5A2B1 M13 M5A2	0.10 0.036	 8796866 8860550	[illegible] [illegible]	
3	OBS	11756003	M318A1C	AP-T	44.2	75-1-375	PA-PD-65	Guns M1, M2, Ser. M36, M41, M54	–	–	–	–	Tracer M5A2B1	0.10	8796866	[illegible]	
4	OBS	11756003	M82	APC-T	42.75	75-1-145	PA-PD-168	Guns M1, M2, Ser. M36 M41 M54	75-14-334	Exp D	0.31	75-14-334	–	–	–	75-18-40	
5	STD	9575	M580	APERS-T	41.25	9216454	PA-PD-2857	Guns M36 M41 M54	9216455	Flch 11/	4.5	9211486	Tracer M13 Red	0.13	8860550	9216427	
6	CON	11756003	M336	Cstr	41.6	9214203	MIL-C-20353	Guns M1, M2 Ser. M36 M41 M54	–	Slug 7/	14.9	10535895	–	–	–	10535895	
7	CON	11756003	M377	Cstr	39.30	9214706	PA-PD-2819	Guns M36 M41 M54	9214707	Flch 8/	6.6	9211486 9212528	–	–	–	9214707	
8	STD	8601	M590 10/	Cstr	6.79	9214567	PA-PD-2807 Ref	Rifle M67	9214568	Flch 9/	2.6	9211486	–	–	–	9214568	

CHART 7. 90-MILLIMETER AMMUNITION

BODY			FUZE			PROPELLING ASSEMBLAGE								PERFORMANCE		PACKING	
						CARTRIDGE CASE		PROPELLANT			PRIMER						
MATERIAL	MATERIAL FORM	DWG NO.	DESIGNATION	TYPE	DWG NO.	DESIGNATION	DWG NO.	COMPOSITION	NOMINAL WT (LB)	DWG NO.	DESIGNATION	TYPE	DWG NO.	MAX RANGE (YD/m)	MV (fps/mps)	INNER PACK DWG NO.	OUTER PACK DWG NO.
Steel	Bar	75-16-44	–	–	–	M19	7548413	M6	7.31	75-1-136	M28A2 M28B1	Perc	8838129 8838130	12,325 (11,270 m)	2,700 (823 mps)	7548301	7548306
Steel	Bar	75-2-545 10522525	–	–	–	M108B1 M106 M19 M19B1	7548028 7548257	M6 M17 M30	8.6	75-1-368 9207966	M49 (T33) M58	Perc	8838153	21,400 (19,568 m)	2,800 (853 mps)	7548467	7548476
Steel	Bar	75-2-543	–	–	–	M19 M19B1	7548413 7548080	M6	8.6	75-1-357	M49	Perc	8839472	21,400 (19,568 m)	2,800 (853 mps)	7548467	7548476
Steel	Forged or Bar	75-16-47	M68 M68A1	BD	73-2-181	M19	7548413	M6	7.31 1/ 8.06 2/	75-1-145	M28A2 M49	Perc	8838129 8839472	21,400 (19,568 m)	2,600 (792 mps) 1/ 2,800 (853 mps) 2/	76-1-604	76-1-672
Steel Alum.	Bar	9216466	M711	MT	10542845	M200	10535933	M6	9.0	9216454	M56	Perc	8838153	4,800 (4,389 m)	3,000 (914 mps)	9213660	9213661
Steel	Tubing	10535897	–	–	–	M108B1	7548029	M2	6	9214203	M56	Perc	8838153	Eff. 200 (183 m)	2,870 (875 mps)	9215119	9215116
Steel	Tubing	9214712	–	–	–	M108B1	7548028	M6	9.0	9214706	M56	Perc	8838153	Eff. 440 (402 m)	2,950 (899 mps)	8798640	8798641
Alum.	Formed Sheet	9225941	–	–	–	M112	8595496	M5	1.5	9214569	M92	Perc	8863394	Eff. 328 (299 m)	1,200 (366 mps)	9213611	9213612

CHART 7. 90-MILLIMETER AMMUNITION
(Continued)

	CARTRIDGE								PROJECTILE							
										FILLER			COMPONENTS			
LINE NO.	TYPE CLASSI-FICA-TION	MSR, AMCTCM OR OTCM NO.	MODEL DESIG-NATION	TYPE	NOMINAL WT (LB)	ASSEMBLY DWG NO.	SPEC NO.	MODEL OF CANNON	PROJEC-TILE ASSEMBLY DWG NO.	COM-POSI-TION	WT (LB)	DWG NO.	KIND	WT (LB)	DWG NO.	METAL PARTS ASSEMBLY DWG NO.
9	OBS OBS CON	11756003	M12 M12B1 M12B2	Dummy	42.04 44.00	72-3-76	–	Guns M1, M2 Ser. M36 M41 M54	–	–	–	–	–	–	–	–
10	CON	11756003	M71	HE	41.19	75-1-184	MIL-C-46226	Guns M1, M2 Ser. M36, M41, M54	75-14-446	Comp B TNT	1.68 1.6	75-14-446	Suppl Chg	0.365	8797090	75-15-42
11	CON	11756003	M71	HE	39.45	75-1-246	MIL-C-46226	Guns M1, M2 Ser. M36, M41, M54	75-14-446	Comp B TNT	1.68 1.6	75-14-446	Suppl Chg	0.365	8797090	75-18-42
12	CON	11756003	M71	HE	41.50	75-1-157	MIL-C-46226	Guns M1, M2 Ser. M36, M41, M54	75-14-305	Comp B TNT	2.15	75-14-305	–	–	–	75-15-42
13	CON	11756003	M71	HE	41.43	75-1-207	MIL-S-46226	Guns M1, M2 Ser. M36 M41 M54	75-14-446	Comp B TNT	2.15	75-14-446	Suppl Chg	0.365	8797090	75-18-42
14	CON	11756003	M71	HE	41.14	75-1-375	MIL-C-46226	Guns M1, M2 Ser. M36 M41 M54	75-14-446	Comp B TNT	2.15	75-14-446	Suppl Chg	0.365	8797090	75-15-42
15	OBS	9381	M591	HE	13.3	P-9209941	PA-PD-2784	Rifle M67	8839444 3/	Comp B	2.1	8839444	–	–	–	8596986
16	CON	6267	M348A1	HEAT	34.79	75-1-359	PA-PD-12	Guns M1, M2 Ser. M36 M41 M54	75-14-700	Comp B	1.56	75-14-700	–	–	–	75-2-575

CHART 7. 90-MILLIMETER AMMUNITION (Continued)

BODY			FUZE			PROPELLING ASSEMBLAGE								PERFORMANCE		PACKING	
						CARTRIDGE CASE		PROPELLANT			PRIMER						
MATERIAL	MATERIAL FORM	DWG NO.	DESIGNATION	TYPE	DWG NO.	DESIGNATION	DWG NO.	COMPOSITION	NOMINAL WT (LB)	DWG NO.	DESIGNATION	TYPE	DWG NO.	MAX RANGE (YD/m)	MV (fps/mps)	INNER PACK DWG NO.	OUTER PACK DWG NO.
Manganese Bronze	Casting	72-3-77	M30	Dummy	72-5-13	–	–	–	–	–	–	–	–	–	–	76-1-603	7548306
Steel	Forged	75-20-92	M51A5	PD	8796862	M19 M19B1	7548413 7548080	M6 Flashless Smokeless	7.31	75-1-184	M28B2 M28A2	Perc	8838130 8838129	19,375 (17,716 m)	2,700 (823 mps)	7548301	7548306
Steel	Forged	75-20-92	M557	PD	8863535	M19 M19B1	7548413 7548080	M6 Flashless Smokeless	7.31	75-1-246	M28B2 M28A2	Perc	8838130 8838129	19,375 (17,716 m)	2,700 (823 mps)	7548301	7548306
Steel	Forged	75-20-92	M51A5	PD	8796862	M19 M19B1	7548413 7548080	M15 Flashless Smokeless	7.31	75-1-257	M49	Perc	8839472	19,375 (17,716 m)	2,700 (823 mps)	7548301	7548306
Steel	Forged	75-20-92	M557	MTSQ	8863535	M19 M19B1	7548413 7548080	M15 Flashless Smokeless	7.31	75-1-207	M49B1	Perc	8839472	19,475 (17,808 m)	2,700 (823 mps)	7548301	7548306
Steel	Forged	75-20-92	M51A5	PD	8796862	M19 M19B1	7548413 7548080	M6 Flashless Smokeless	7.31	75-1-375	M28B2 M28A2	Perc –	8838130 8839129	19,475 (17,808 m)	2,700 (823 mps)	7548301	7548306
Iron	Pelitic Malleable	8596989	M593	PD	9211809	M112	8595496	M5	1.25	9212287	XM92E1	Perc	8863394	1,810 (1,655 m)	470 (143 mps)	8796717	8796716
Steel	Forged	75-2-578	M509A1	PIBD	8799735	T27E2	7548087	M6	5	75-1-359	T69	Perc	74-2-114	13,010 (11,896 m)	2,800 (853 mps)	8887601	8887602

CHART 7. 90-MILLIMETER AMMUNITION (Continued)

CARTRIDGE									PROJECTILE							
										FILLER			COMPONENTS			
LINE NO.	TYPE CLASSI-FICA-TION	MSR, AMCTCM OR OTCM NO.	MODEL DESIG-NATION	TYPE	NOMINAL WT (LB)	ASSEMBLY DWG NO.	SPEC NO.	MODEL OF CANNON	PROJEC-TILE ASSEMBLY DWG NO.	COM-POSI-TION	WT (LB)	DWG NO.	KIND	WT (LB)	DWG NO.	MODEL PARTS ASSEMBLY DWG NO.
17	STD	4265	M371A1	HEAT	9.25	8863468	MIL-C-46467	Rifle M67	8863469	Comp B	1.72	8863469	–	–	–	8595478
18	STD	4265	M371E1	HEAT	9.28	8844542	MIL-C-46467	Rifle M67	8846857	Comp B	1.72	8846857	–	–	–	8595478
19	STD STD STD	8823	M431A2 M431A1 M431	HEAT-T	33	8822481	MIL-C-45491	Guns M36 M41 M54	8822480	Comp B	1.2	8822480	Tracer M13	0.036	8860550	8594965
20	STD	37436	M71A1	HE-T	38.6 39.54	8849017-1	MIL-C-46226	Guns M36 M41 M54	8849016-1	Comp B TNT	2.15	8849016-1	Tracer XM10	0.009	8849013	75-16-42
21	OBS	37119	M304	HVAP-T	35.82	75-1-234	MIL-C-20608	Guns M1, M2 Ser. M36 M41 M54	75-14-3	–	–	–	Tracer M5A2B1	0.10	8796866	75-2-375
22	CON	11756003	M332A1	HVAP-T	32.30	75-1-310	MIL-C-20608	Guns M1, M2 Ser. M36 M41 M54	–	–	–	–	Tracer M5A2B1	0.10	8796866	75-2-479
23	STD	37136	M371	Prac.	9.25	8865243	MIL-C-46927	Rifle M67	8865242	Inert Filler E	1.79	8865242	–	–	–	8595478

CHART 7. 90-MILLIMETER AMMUNITION
(Continued)

BODY			FUZE			PROPELLING ASSEMBLAGE								PERFORMANCE		PACKING	
						CARTRIDGE CASE		PROPELLANT			PRIMER						
MATERIAL	MATERIAL FORM	DWG NO.	DESIGNATION	TYPE	DWG NO.	DESIGNATION	DWG NO.	COMPOSITION	NOMINAL WT (LB)	DWG NO.	DESIGNATION	TYPE	DWG NO.	MAX RANGE (YD/m)	MV (fps/mps)	INNER PACK DWG NO.	OUTER PACK DWG NO.
Alum.	–	8595492	M530A1	PIBD	10980600	M112	8595496	M5	1.31	8848806	M92 M92A1	Perc	8863394	2,292 (2,095 m)	700 (213 mps)	8796717	8796716
Alum.	–	8595492	M530	PIBD	10404054	M112	8595496	M5	1.31	8848806	M76	Perc	8847520	2,292 (2,095 m)	700 (213 mps)	8796717	8796716
Steel	Forged	8595972	M509A1	PIBD	8799735	M114A1	8595505	M30	8.25	8822481	M79	Perc	8839485	8,900 (8,138 m)	4,000 (1,219 mps)	8800078	8800077
Steel	Forged	75-20-92	M557	PD	8863535	M19B1 M19	7548080 7548413	M1 Flashless Smokeless	5.31	8849017	M28B2 M28A2	Perc	8836130 8838129	17,300 (15,819 m)	2,400 (731 mps)	7548301	7548306
Alum.		75-2-375	–	–	–	M19 M19B1	7548413 7548080	M6 Smokeless Flashless	8.4	75-1-234	M40A1	Perc	8839471	15,130 (13,835 m)	3,350 (1,021 mps)	76-1-1106	76-1-1237
Alum. Alloy Tungsten Carbide	Forged	75-2-481	–	–	–	M19 M19B1	7548413 7548080	M17	8.5	75-1-310	M49	Perc	8839472	15,700 (14,356 m)	3,875 (1,181 mps)	76-1-1106	76-1-1237
Alum. Alloy		8595492	M530	PIBD	10404054	M112	8595496	M5	1.3	8848806	XM92	Perc	8863394	Eff. Range 400	(213 mps)	8796717	8796716

CHART 7. 90-MILLIMETER AMMUNITION (Continued)

CARTRIDGE									PROJECTILE							
										FILLER			COMPONENTS			
LINE NO.	TYPE-CLASSI-FICA-TION	MSR, AMCTCM OR OTCM NO.	MODEL DESIG-NATION	TYPE	NOMINAL WT (LB)	ASSEMBLY DWG NO.	SPEC NO.	MODEL OF CANNON	PROJEC-TILE ASSEMBLY DWG NO.	COM-POSI-TION	WT (LB)	DWG NO.	KIND	WT (LB)	DWG NO.	MODEL PARTS ASSEMBLY DWG NO.
24	CON	11756003	M313	Smoke WP	42.52	75-1-224	MIL-S-3139	Guns M1, M2 Ser M36 M41 M54	75-14-501	WP	1.97	75-14-501	Burster M24 4/	2.33 oz.	73-1-211	75-2-369
25	STD	37619	M313C	Smoke WP	40.52	8858640	MIL-C-46226	Guns M36 M41 M54	75-14-501	WP	1.97	75-14-501	Burster M24 4/	2.33 oz.	73-1-211	75-2-369
26	OBS	37119	M71	TP	42.04	75-1-163	–	Guns M1, M2 Ser M36 M41 M54	–	Inert Mat'l	2.15	75-1-163	–	–	–	75-18-42
27	OBS	11756003	M353A1 M353	TP-T	43.91	8861603	MIL-C-45096	Guns M36 M41 M54	–	–	–	–	Tracer Proj M13 M5A2 M5A2B1	0.036	8860550	10522528
28	STD	02766007	M764	TP-T	21.00	9297850	MIL-C-48758	M36 M41 M54	9297851	Inert Type 2	2.15	MIL-I-60350	Tracer M10	0.009	8849014	75-18-42D

1/ w/M28A2 Primer, Propellant, Flashless-Smokeless.
2/ w/M49 Primer.
3/ 81MM, 3.362A1 Loading A'ssy.
4/ Contains Burster, Casing M13, Dwg 73-1-212 and Burster, Initiator, M2 Dwg 8830869.
5/ w/M49 Primer.
6/ w/M28A2 or M28B2 Primer.
7/ Contains 1281, steel slugs
8/ Contains 5600 flechettes.
9/ Contains 2400 flechettes.
10/ XM590E1 Differs in Nose end design - flat bottom, scored metal cup crimped to projectile body instead of cloven plastic plug and contains 2400 flechettes.
11/ Contains 4200 flechettes.

CHART 7. 90-MILLIMETER AMMUNITION
(Continued)

BODY			FUZE			PROPELLING ASSEMBLAGE									PERFORMANCE		PACKING	
						CARTRIDGE CASE		PROPELLANT			PRIMER							
MATERIAL	MATERIAL FORM	DWG NO.	DESIGNATION	TYPE	DWG NO.	DESIGNATION	DWG NO.	COMPOSITION	NOMINAL WT (LB)	DWG NO.	DESIGNATION	TYPE	DWG NO.	MAX RANGE (YD/m)	MV (fps/mps)	INNER PACK DWG NO.	OUTER PACK DWG NO.
Steel	Forged	75-2-370	M48A3	PD	8798219	M19 M19B1	7548413 7548080	M15 M6	7.31	75-1-224	M49 M28B2	Perc	8839472 8838130	19,375 (17,716 m)	2,700 (823 mps)	7648301	7548306
Steel	Forged	75-2-370	M48A3	PD	8798219	M19B1	7548080	M1	5.33	8858640	M28B2 M28A2	Perc	8838130 8838129	16,800 (15,362 m)	2,400 (731 mps)	7548301	7548306
Steel	Forged	75-20-92	M73	Dummy	8796863	M19 M19B1	7548413 7548080	M15 5/ M16 6/	7.31	75-1-163	M49 M28A2 M28B2	Perc	8839472 8838129 8838130	19,375 (17,716 m)	2,700 (823 mps)	76-1-602	76-1-1236
Steel	Bar	10522528	–	–	–	M108 M108B1	7548028 7548257	M30	8.6	8861603	M58	Perc	8838153	23,000 (21,031 m)	3,000 (914 mps)	7548467	7548476
Steel	Forged	75-20-92	–	–	–	M19B1	7548080	M1	5.3	8849017	M28B2	Perc	8838130	–	–	7548301	7548306

CHART 8. 105-MILLIMETER AMMUNITION

LINE NO.	CARTRIDGE: TYPE-CLASSIFICATION	CARTRIDGE: MSR, AMCTCM OR OTCM NO.	CARTRIDGE: MODEL DESIGNATION	CARTRIDGE: TYPE	CARTRIDGE: NOMINAL WT (LB)	CARTRIDGE: ASSEMBLY DWG NO.	CARTRIDGE: SPEC NO.	CARTRIDGE: MODEL OF CANNON	PROJECTILE: PROJECTILE ASSEMBLY DWG NO.	PROJECTILE: FILLER: COMPOSITION	PROJECTILE: FILLER: WT (LB)	PROJECTILE: FILLER: DWG NO.	PROJECTILE: COMPONENTS: KIND	PROJECTILE: COMPONENTS: WT (LB)	PROJECTILE: COMPONENTS: DWG NO.	PROJECTILE: METAL PARTS ASSEMBLY DWG NO.	N
1	STD	36841	M60	Agent	42.92	75-1-109	MIL-C-3139	How* M2A1 M2A2 M4 M4A1 M49 M137	75-14-273 9217215	HD	2.97 or 3.17	75-14-273	Burster Chg M5 Casing M5	0.51	10535931 10535946	10535930	S
2	STD	37119	M360	Agent	43.86	75-1-363	MIL-C-3139	How M2A1 M2A2 M103 M4 M4A1 M49 M137	75-14-705	GB Non-Pers	1.63	75-14-705	Burster Chg, M40 Casing M16	1.90	75-1-256 8880479 75-1-257	75-4-209	S
3	STD 1/ STD 2/	38116	M392A2 1/ M392A1 2/	APDS-T	41.0	8863427 1/ 8799900 2/	MIL-C-46216	Gun M68	8863426 1/ 8799894 2/	Penetrator 3/	– –	8595464 –	Tracer M13	0.036	8860550	8595461	S
4	STD	02787001	M728	APDS-T	42.0	9276810	MIL-C-48237	Gun M68	9287564	Penetrator 3/	–	11738350	Tracer M13	0.036	8860550	11738343	S
5	STD	9575	M494	APERS	55.0	9229962	MIL-C-14747	Gun M68	9229964	Flch 13-gr Steel	9.2	9219980	Tracer M13	0.036	8860550	9229966	A S
6	STD	09736030	M546	APERS-T	38.25	9211669	PA-PD-2789 MIL-C-50252	How M2A1 M2A2 M103 M137	9211471 Designation XM380E5	Flch 6-gr Steel	9.145	9211486	Tracer M13	0.036	8860550	9211480	A S
7	STD	02789001	M735	APFSDS-T	38.00	9296707	MIL-C-63055	M68	9331316	Penetrator 3/	–	9312505	Tracer M13	0.036	8860550	9331316	S
8	STD	36841	M14	Dummy	42.06	72-3-76	–	How* M2A1 M2A2 M49	–	–	–	–	–	–	–	72-3-79	S N al I
9	STD	639	M457	Dummy	44.0	10534154	FA-PD-MI-2608	Gun M68	–	–	–	–	–	–	–	10534162	S
10	STD	4181	M1	HE	42.0	75-1-75	MIL-C-45195	How* M2A1 M2A2 M4 M4A1 M49	75-14-206	Comp B TNT	5.09 4.80	75-14-206	Closing Plug	0.37	75-14-40 8797490	75-4-75	S

CHART 8. 105-MILLIMETER AMMUNITION

BODY			FUZE			PROPELLING ASSEMBLAGE									PERFORMANCE		PACKING	
						CARTRIDGE CASE		PROPELLANT			PRIMER							
MATERIAL	MATERIAL FORM	DWG NO.	DESIGNATION	TYPE	DWG NO.	DESIGNATION	DWG NO.	COMPOSITION	NOM WT (LB)	DWG NO.	DESIGNATION	TYPE	DWG NO.	MAX RANGE YD (m)	MV fps (mps)	INNER PACK DWG NO.	OUTER PACK DWG NO
Steel	Forged	10535941	M557 M739 8/	PD PD	8863535 9258602	M14 M14B1	7548409 7548025	M1	2.75	9205472	M28A2 M28B2	Perc	8838129 8838130	12,330 (11,270 m)	1,550 (472.4 mps)	7549073	7549072
Steel	Forged or Bar	75-4-210	M557 M739	PD	8863535 9258602	M14 M14B1	7548409 7548025	M1	2.75	9205472	M28A2 M28B2	Perc	8838129 8838130	12,330 (11,270 m) 12,590 yds (11,500 m)	1,550 (472.4 mps) 1,621 fps (494 mps)	7549073	7549072
Sabot 3/	Magnesium Alloy	8595476 3/	–	–	–	M115B1 M115	10520214 8597490	M30	12.0	8863427	M80A1	Elec	8839499	40,162 (36,146 m)	4,850 (1,479 mps)	8835040	8835039
Sabot 3/	Magnesium Alloy	11738346	–	–	–	M115B1	10520214	M30	12.0	MIL-P-48266	M80A1	Elec	8839499	–	4,680	8835040	8835039
Alum Steel	Forged	9229967	M571	MT	10551670	M150B1 M150	10521648 8597473	M6	9.2	9229962	M86	Elec	8847424	4,840 (4,400 m)	2,700 (821 mps)	9204453	9204454
Alum Steel	—	9211531	M563 Series	MT	10520688	M14B4 Series	8595386	M30E1 M30A1	3.1	9211657	M90	Perc -	8866664	328 (295 m) 6/	5/	8862348	8862347
Sabot	Alum.	9331314	–	–	–	M148A1B1	10522799	M30	12.5	MIL-P-63105	M120	Elec	9296617	–	4,925	9293481	9293479
Steel Malleable Iron	Forged Bronze Casting	72-3-79	M59	Dummy PD	72-5-5	M14 Series	–	Propelling Chg. M3 Dummy	3.10	72-2-64 8865039	M1B1	Inert Perc	8839474	–	–	7549073	7549072
Steel	Bar	10534163	–	–	–	M148A1 B1	10522799	–	–	–	–	–	–	–	–	8836005	8836004
Steel	Forged	75-20-76	M557 M564 M739 8/	PD MTSQ PD	8863535 10534285 9258602	M14 M14B1	75-8409 75-8025	M1	2.75	9205472	M28A2 M28B2	Perc	8838129 8838130	12,330 (11,270 m) 12,590 yds (11,500 m)	1,550 (472.4 mps) 1,621 fps (494 mps)	7549073	7549072

CHART 8. 105-MILLIMETER AMMUNITION
(Continued)

	CARTRIDGE								PROJECTILE								
										FILLER			COMPONENTS			
LINE NO.	TYPE-CLASSI-FICA-TION	MSR, AMCTCM OR OTCM NO.	MODEL DESIG-NATION	TYPE	NOMINAL WT (LB)	ASSEMBLY DWG NO.	SPEC NO.	MODEL OF CANNON	PROJEC-TILE ASSEMBLY DWG NO.	COM-POSI-TION	WT (LB)	DWG NO.	KIND	WT (LB)	DWG NO.	METAL PARTS ASSEMBLY DWG NO.
11	STD	4181	M1	HE	42.0	75-1-91	MIL-C-45195	How* M2A1 M2A2 M4 M4A1 M49	75-14-206	Comp B TNT	5.08 4.80	75-14-206 9211610	Closing Plug	0.37	75-14-40 8797490	75-4-75
12	STD	4181	M1	HE	42.93	75-1-185	MIL-C-45195	How* M2A1 M2A2 M4 M4A1 M49	9211610	Comp B TNT	4.60 4.25	9211610	Suppl Chg	0.3	8797090	75-4-75
13	STD	4181	M1	HE	39.92	9211611	MIL-C-45195	How* M2A1 M2A2 M4 M4A1 M49 M103 M137	9211610	Comp B TNT	4.60 4.25	9211610	Suppl Chg Closing Plug	0.365 0.3 0.37	8797090	10535876
14	OBS	37119	M323	HE	48.59	75-1-263 75-1-264	MIL-C-12870	Rifles M27 M27A1	75-14-618	Comp B TNT	4.38 4.61	75-14-618	Suppl Chg	0.365	8797090	75-4-174
15	OBS	11756003	M413 (T377E1)	HE	42.0	XP97090	AEI-17	How M2A1 M2A2 M49	FXP 94957	Comp B	1.1	XP 94930	18 M35	10.4	XP94930	XP97193
16	STD	37803	M444	HE	42.0	8864930	AEI-68	How M2A1 M2A2 M49 M103 M137 M137E1	8864931	A5	0.93	8864945	Grenade 18 M39	10.4	8864945	9864932
17	OBS	6418	M341	HEAT	37.10	75-1-313	MIL-C-12631	Rifle M27A1	75-14-661	Comp B	2.38	75-14-655	–	–	–	75-2-501
18	OBS	6418	M324	HEAT-T	46.1	75-1-266	PA-PD-96	Rifle M27 M27A1	75-14-619	Comp B	3.06	75-14-619	Tracer M5A2B1	0.10	8796866	75-4-175
19	STD OBS STD LP	4677 11756003 11756003 08786019	M456A1 M456 M456E1 M456A2 (M456A1E2)	HEAT-T HEAT-T-MP	48.0 49.1	8861065 9312815	MIL-C-46457 MIL-C-63286	Gun M68	8861071 9312815	Comp B Comp B	2.14 2.14	8861071 9327408	Tracer Projectile M13	0.013 0.013	8860550 8860850	8597604 9323824

CHART 8. 105-MILLIMETER AMMUNITION
(Continued)

BODY			FUZE			PROPELLING ASSEMBLAGE								PERFORMANCE		PACKING	
						CARTRIDGE CASE		PROPELLANT			PRIMER						
MATERIAL	MATERIAL FORM	DWG NO.	DESIGNATION	TYPE	DWG NO.	DESIGNATION	DWG NO.	COMPOSITION	NOM WT (LB)	DWG NO.	DESIGNATION	TYPE	DWG NO.	MAX RANGE YD (m)	MV fps (mps)	INNER PACK DWG NO.	OUTER PACK DWG NO.
Steel	Forged	10521644	M509A1	PIBD	8799735	M201	11820669	M30	3.55	MIL-P-668	M100	Perc	9277103	—	—	8876101	8876100
Steel	Forged	75-4-193	M91A1	BD	8837305	M32	71-2-141	M10	7.70	75-1-296	M57	Perc	8838009	8,260 (7,434 m)	1,250 (381 mps)	76-1-1342	7549148
Steel	Forged	75-2-498	M91	BD	8837308	M14 M14B1	7548409 7548025	M6	3.90	71-9-269	M28A2 M28B2	Perc	8838129 8838130	9,100 (8,190 m)	1,835 (559.7 mps)	7549073	7549072
Steel	Forged	75-2-522 8596146	M91A1	BD	8837305	M95B1	71-2-188	M10	8.25	75-1-323	M57	Perc	8838009	750 (675 m)	1,690 (515.5 mps)	7549071	7549070
Steel	Bar	8597103	M534A1	BD	8860724	M150B1 M150	10521648 8597493	M1	5.9	8853734	M86	Elec	8847424	10,400 (9,360 m)	2,400 (732 mps)	8836005	8836004
Steel	Bar	10524307	M576	BD	8886434	M150B1 M150	10521648 8597493	M1	5.9	8853734	M86	Elec	8847424	10,400 (9,360 m)	2,400 (732 mps)	8836005	8836004
Steel	High Carbon		M739 M557 M582 M728	PD MTSQ PROX	9258602 8863535 9236701 11718400	M14B4 M14B1 M14	8595386 7548025 7548409	M30A1	2.75	9212377	M106	Perc	9212386	15,000	1,800	9212636	9212637
Steel	Forged (M314-A2) Tube (M314-A2B1)	75-4-129 75-2-542	M501A1	MTSQ	73-7-136	M14 M14B1	7548409 7548025	M1	2.8	9205472	M28A2 M28B2	Perc	8838129 8838130	12,330 (11,270 m) 12,590 (11,500 m)	1,550 (472.4 mps) 1,621 (494 mps)	7549073	7549072
Steel Tubing	Forged	10534902	M565 M577	MT MTSQ	10522991 9236500	M14B4 3E1 M14	8595386 7548409	M6	2.8	9205472	M28A2 M28B2	Perc	8838129 8838130	12,330 (11,270 m) 12,590 yds (11,500 m)	1,550 (472.4 mps) 1,621 (494 mps)	7549073	7549072
Steel	Forged	75-4-111	M501A1	MTSQ	73-7-136	M14B1 M14	7548025 7548409	M1	2.75	9205472	M28A2 M28B2	Perc	8838129 8838130	9,943 (6,949 m)	1,422 (433.7 mps)	7549073	7549072

CHART 8. 105-MILLIMETER AMMUNITION (Continued)

CARTRIDGE									PROJECTILE							
										FILLER			COMPONENTS			
LINE NO.	TYPE-CLASSI-FICA-TION	MSR, AMCTCM OR OTCM NO	MODEL DESIG-NATION	TYPE	NOMINAL WT (LB)	ASSEMBLY DWG NO.	SPEC NO.	MODEL OF CANNON	PROJEC-TILE ASSEMBLY DWG NO.	COM-POSI-TION	WT (LB)	DWG NO.	KIND	WT (LB)	DWG NO.	METAL PARTS ASSEMBLY DWG NO.
20	STD	06786019	M622	HEAT-T	32.1	9282517	MIL-P-63208	How M2A1 M2A2 M103 M137	9282518	Comp B	2.14	MIL-C-401	Tracer M13	0.036	8860850	9282519
21	OBS	11756003	M326	HEP-T	41.3	75-1-296	PA-PD-93	Rifle M27 M27A1	75-14-637	Comp A-3	7.5	75-14-637	Tracer M5A2B1	0.10	8796866	75-4-189
22	STD	36841	M327	HEP-T	33.45	75-1-362	MIL-C-42650	How* M2A1 M2A2 M4 M4A1 M49 M103 M137	75-14-702	Comp A-3	7.6	75-14-702	Tracer M5A2B1	0.10	8796866	75-2-497
23	OBS	6416	M345	HEP-T	37.37	75-1-323	PA-PD-93	Rifle M27 M27A1	75-14-667	Comp A-3	7.72	75-14-667	Tracer M5	0.10	8796866	75-2-521
24	STD	3325	M393A1	HEP-T	45.0	8853736	MIL-C-46492	Gun M68	8853735	Comp A-3	6.4	8853735	Tracer M12	0.04	8853698	8597104
25	STD	3325	M393A2	HEP-T	45.0	8886470	MIL-C-60039	Gun M68	886469	Comp A-3	6.0	8886469	Tracer Projectile M12	0.04	8853698	10524305
26	STD 7/	8414	M548	HERA	38.5	9212376	MIL-C-60932	M2A1 M2A2 M103 M137	9212389	Comp B	5.2	9212390	Suppl Chg	0.3	8797090	9212394
27	C&T	7467	M314A2 M314A M314	Illum	46.43	75-1-229	MIL-C-20354	How* M2A1 M2A2 M4 M4A1 M49	75-14-508	Illum	1.74	9206749	Chg 1st Fire	0.13	9206749	75-4-128
28	STD	7467	M314A3	Illum	46.43	9206821	MIL-C-20354	How* M2A1 M2A2 M4A1 M49	9206744	Illum	1.97	9251740	Chg 1st Fire	0.15	9351741	10534900
29	OBS	11756003	M84 M84B1	Leaflet	39.7	9219187	MIL-C-20426	How* M2A1 M2A2 M4 M4A1 M49	9218520	Leaflets replaces smoke canister			Burster Chg BP	0.14		75-4-105

CHART 8. 105-MILLIMETER AMMUNITION (Continued)

BODY			FUZE			PROPELLING ASSEMBLAGE								PERFORMANCE		PACKING	
						CARTRIDGE CASE		PROPELLANT			PRIMER						
MATERIAL	MATERIAL FORM	DWG NO.	DESIGNATION	TYPE	DWG NO.	DESIGNATION	DWG NO.	COMPOSITION	NOM WT (LB)	DWG NO.	DESIGNATION	TYPE	DWG NO.	MAX RANGE YD (m)	MV fps (mps)	INNER PACK DWG NO.	OUTER PACK DWG NO.
Steel	Forged	10521644	M509A1	PIBD	8799735	M201	11820669	M30	3.55	MIL-P-668	M100	Perc	9277103	–	–	8876101	8876100
Steel	Forged	75-4-193	M91A1	BD	8837305	M32	71-2-141	M10	7.70	75-1-296	M57	Perc	8838009	8,260 (7,434 m)	1,250 (381 mps)	76-1-1342	7549148
Steel	Forged	75-2-498	M91	BD	8837308	M14 M14B1	7548409 7548025	M6	3.90	71-9-269	M28A2 M28B2	Perc	8838129 8838130	9,100 (8,190 m)	1,835 (559.7 mps)	7549073	7549072
Steel	Forged	75-2-522 8596146	M91A1	BD	8837305	M95B1	71-2-188	M10	8.25	75-1-323	M57	Perc	8838009	750 (675 m)	1,690 (515.5 mps)	7549071	7549070
Steel	Bar	8597103	M534A1	BD	8860724	M150B1 M150	10521648 8597493	M1	5.9	8853734	M86	Elec	8847424	10,400 (9,360 m)	2,400 (732 mps)	8836005	8836004
Steel	Bar	10524307	M578	BD	8886434	M150B1 M150	10521648 8597493	M1	5.9	8853734	M86	Elec	8847424	10,400 (9,360 m)	2,400 (732 mps)	8836005	8836004
Steel	High Carbon		M739 M557 M582 M728	PD MTSQ PROX	9258602 8863535 9236701 11718400	M14B4 M14B1 M14	8595386 7548025 7548409	M30A1	2.75	9212377	M106	Perc	9212386	15,000	1,800	9212636	9212637
Steel	Forged (M314-A2) Tube (M314-A2B1)	75-4-129 75-2-542	M501A1	MTSQ	73-7-136	M14 M14B1	7548409 7548025	M1	2.8	9205472	M28A2 M28B2	Perc	8838129 8838130	12,330 (11,270 m) 12,590 (11,500 m)	1,550 (472.4 mps) 1,621 (494 mps)	7549073	7549072
Steel Tubing	Forged	10534902	M565 M577	MT MTSQ	10522991 9236500	M14B4 3E1 M14	8595386 7548409	M67	2.8	9205472	M28A2 M28B2	Perc	8838129 8838130	12,330 (11,270 m) 12,590 yds (11,500 m)	1,550 (472.4 mps) 1,621 (494 mps)	7549073	7549072
Steel	Forged	75-4-111	M501A1	MTSQ	73-7-136	M14B1 M14	7548025 7548409	M1	2.75	9205472	M28A2 M28B2	Perc	8838129 8838130	9,943 (6,949 m)	1,422 (433.7 mps)	7549073	7549072

CHART 8. 105-MILLIMETER AMMUNITION (Continued)

	CARTRIDGE								PROJECTILE							
										FILLER			COMPONENTS			
LINE NO.	TYPE-CLASSI-FICA-TION	MSR, AMCTCM OR OTCM NO.	MODEL DESIG-NATION	TYPE	NOMINAL WT (LB)	ASSEMBLY DWG NO.	SPEC NO.	MODEL OF CANNON	PROJEC-TILE ASSEMBLY DWG NO.	COM-POSI-TION	WT (LB)	DWG NO.	KIND	WT (LB)	DWG NO.	METAL PARTS ASSEMBLY DWG NO.
30	CON	11756003	M84 M84B1	4/	41.96	9219187-2	MIL-C-20418	How* M2A1 M2A2 M4 M4A1 M49	9218520-2 9218520-3 9218520-4 9218520-5	4/ Smoke Colored	4/	C15-11-60	Chg BP	0.15	9218512	75-4-105
31	CON STD STD	11756003 9102 9102	M60 M60A1 M60A2	Smoke	43.81 42.92 41.71	75-01-110 9216521 9257991	MIL-C-3139 MIL-C-60380 MIL-C-60380	How* M2A1 M2A2 M4 M4A1 M49	9217215 9216522 9216522 9216522	WP WP WP	3.83 3.85 3.35	9217215 9225939 9225939	Burster Chg M5 Casing M5 M53 M53A1	0.21 0.21 0.21	10535931 10535948 9223129	10535930 10535930
32	STD	36841	M84 M84B1	Smoke	41.93	9219187-1	MIL-C-20418	How* M2A1 M2A2 M4 M4A1 M49	9218520-1	HC	7.50	C15-11-22	Expelling Chg BP	0.15	9218512	75-4-105
33	STD	7621	M84A1	Smoke	40.5	9223431-1	MIL-C-20418	How M2A2 M103 M107	9223430-1	HC	12.3	C15-11-12	Expelling Chg	0.11	9207912	10542988
34	STD	2173	M416	Smoke	45.5	9886487	MIL-C-46956	Gun M68	8886486	WP	6.0	8886485	Burster Projec. M48 Tracer Projec. M12	 0.4	8886484 8853698	10522803
35	CON	03736119	M629	Tactical CS	42.0	9220225	MIL-C-60411	How M2A2 M137	9220224	CS	5.66	C15-11-183	Expelling Chg	0.11	9207912	10543036

CHART 8. 105-MILLIMETER AMMUNITION
(Continued)

			FUZE			PROPELLING ASSEMBLAGE								PERFORMANCE		PACKING	
BODY						CARTRIDGE CASE		PROPELLANT			PRIMER						
MATE-RIAL	MATE-RIAL FORM	DWG NO.	DESIG-NATION	TYPE	DWG NO.	DESIG-NATION	DWG NO.	COM-POSI-TION	NOM WT (LB)	DWG NO.	DESIG-NATION	TYPE	DWG NO.	MAX RANGE YD (m)	MV fps (mps)	INNER PACK DWG NO.	OUTER PACK DWG NO
Steel	Forged	75-4-111	M501A1	MTSQ	73-7-136	M14B4 M14B1	8595836 7548025	M1	2.83	9205472	M28A2 M28B2	Perc	8838129 8838130	12,330 (11,270 m) 12,590 yds (11,500 m)	1,550 (472.4 mps 1,621 fps (494 mps)	7549073	7549072
Steel	Forged	10535941	M557 M564 9/	PD MTSQ	8863535 10534285	M14B1 M14	7548025 7548409	M1	2.75	9205472	M28A2 M28B2 M28A2	Perc	8838129 8838130 8838129	12,330 (11,270 m)	1,550 (472.8 mps	7549073	7549072
															1,550	7549073	7549072
Steel	Forged	10535941									M28B2	Perc	8838130	12,330 (11,270 m)	1,550 (472.8 mps	7549073	7549072
Steel	Forged	75-4-111	M501A1	MTSQ	73-7-136	M14B4 M14B1	8595836 7548025	M1	2.75	9205472	M28A2 M28B2	Perc	8838129 8838130	12,330 (11,097 m)	1,550 (472.8 mps	7549073	7549072
Steel	Semi Fin	10542990	M548 M565 M577	MTSQ MT MTSQ	10520638 10522991 9236500	M14B1 M14B4	7548025 8595386	M1	2.75	9205472	M28B2 M28A2	Perc	8838130 8838129	12,330 (11,270 m)	1,330 (405 mps)	7549073	7549072
Steel	Bar	10522805	M534A1	BD	8860724	M150B1 M150	10521648 8597493	M1	5.9	8853734	M86	Elec	8847424	10,000 (9,150 m)	2,400 (730 mps)	8836005	8836004
Steel	Forged	10534901	M548 M565 M577	MTSQ MT MTSQ	10520638 10522991 9236500	M14 Series	8595386	M1	2.75	9205472	M28B2 M28B1	Perc	8838130	12,330 (11,270 m) 12,590 yds (11,500 m)	1,550 (472.4 mps 1,621 fps (494 mps)	7549073	7549072

CHART 8. 105-MILLIMETER AMMUNITION
(Continued)

CARTRIDGE										PROJECTILE							
											FILLER			COMPONENTS			
LINE NO.	TYPE-CLASSI-FICA-TION	MSR, AMCTCM OR OTCM NO.	MODEL DESIG-NATION	TYPE	NOMINAL WT (LB)	ASSEMBLY DWG NO.	SPEC NO.	MODEL OF CANNON	PROJEC-TILE ASSEMBLY DWG NO.	COM-POSI-TION	WT (LB)	DWG NO	KIND	WT (LB)	DWG NO.	METAL PARTS ASSEMBLY DWG NO.	
36	CON	8650	M67	TP-T	37.06	75-1-191	MIL-C-12849	How * M2A1 M2A2 M49	75-14-463	Inert Mat'l	3.89	75-14-463	Tracer M5A2B1	0.10	8796866	75-4-106	
37	STD	0173625	M467	TP-T	45.0	8863618	MIL-C-46665	Gun M68	8863616	Inert Mat'l		—	Tracer Projec. M12	0.04	8853698	10521886	
38	STD STD	1103 06846011	M490 M490A1	TP-T TP-T	45.0 45.81	8865533 9343009	MIL-C-46988 MIL-C-63513	Gun M68	8865533 9329792	Inert Mat'l	— —	— —	Tracer Projec. M13	0.036	8860550	10523473 9329792	
39	STD	05746014	M724A1 and M724	TPDS-T	32.0	9278500	MIL-C-48139	Gun M68	9278499	Inert Mat'l	—	11738370	Tracer M13	0.036	8860530	11738365	
40	STD	12803004	M774	APFSDS-T	38.8	9324880	ANSI Y14.5-1973	Gun M68	9310779	Pene-trator 9/	—	9310779	Tracer M13	0.036	8860550	9329515	
41	STD	DA Ltr 4/83	M833 M833	APFS DS-T	36.2	9342932	MIL-C-63423	Gun M68	9342931	Pene-trator 9	—	9342931	Tracer M13	[illegible]	8860550	[illegible]	
42	STD	09786046	M760	HE	39.92	9289185	MIL-C 63261	BLG L119 10/	9211610.2	TNT	4.6	9211610	—	—	—	10555876	

1/ Applicable to M392A2.
2/ Applicable to M392A1.
3/ Sheath and core assembly, Sintered Tungsten Carbide Core.
4/ Filler Color Filler Wt.
Yellow 4.92
Red 5.21
Green 5.13
Violet 5.13
5/ Muzzle velocity 1700 FPS (519 m) from How M2A2, 1800 FPS from How M103 & M137.
6/ From point of fuze functioning.
7/ Zone 7 only.
8/ Shipped with closing plug in lieu of fuze, preferred fuzes listed.
9/ Depleted Uranium Core.
10/ British Light Gun L119.
* M103, M137.

CHART 8. 105-MILLIMETER AMMUNITION (Continued)

BODY			FUZE			PROPELLING ASSEMBLAGE								PERFORMANCE		PACKING	
						CARTRIDGE CASE		PROPELLANT			PRIMER						
MATERIAL	MATERIAL FORM	DWG NO.	DESIGNATION	TYPE	DWG NO.	DESIGNATION	DWG NO.	COMPOSITION	NOM WT (LB)	DWG NO.	DESIGNATION	TYPE	DWG NO.	MAX RANGE YD (m)	MV fps (mps)	INNER PACK DWG NO.	OUTER PACK DWG NO
Steel	Bar	75-20-94	–	–	–	M14 Series	7548025 7548409	M1	1.54	71-9-204	M28A2 M28B2	Perc	8838126 8838130	8,281 (745 m)	1,250 (381 mps)	7549073	7549072
Steel	Bar	10521886	–	–	–	M150B1 M150	10521646 8597493	M1	5.9	8853734	M86	Elec	8847424	10,400 (9,510 m)	2,400 (730 mps)	8836005	8836004
Steel Steel	Bar Bar	10523475 9329793	– –	– –	– –	M148A1 B1 M148E4 M148A1B1	10522799 8597492 9343010	M30 M14	11.5 11.75	8865257 MIL-P 63517	M83 M80A1	Elec Elec	8847476 8839499	8,975 (8,207 m)	3,850 (1,170 mps)	8837832 9328579	8837831 9328580
Sabot	Magnesium Alloy	11738367	–	–	–	M115B1	10520214	M1	9.0	MIL-P-48154	M80A1	Elec	8839499	1,845 (15,306 m)	5,080 (1,539 mps)	8835040	8835039
Sabot	Alum.	9310777	–	–	–	M148A1 B1	10522799	M30	12.9	MIL-P-46489	M120	Elec	9296617	8,975 (8,207 m)	4950 (1513 mps)	9293481	9293479
Sabot	Alum.	9342924	–	–	–	M148A, B	10522799	M30	12.5	MIL-P-63515	M120	Elec	9296617	–	–	9349242	9345252
Steel	Forged	10535877	M557 M739 M564 M582 M732	PD PD MTSQ MTSQ PROX	8863535 9258602 10534285 9236701 11716451	M14B4	8595386	M30 Type 1	4.5	9282042	M28B2	Perc	8836130	–	–	–	7549072

CHART 9. 106-MILLIMETER AMMUNITION

CARTRIDGE									PROJECTILE							
										FILLER			COMPONENTS			
LINE NO.	TYPE CLASSI-FICA-TION	MSR, AMCTCM OR OTCM NO.	MODEL DESIG-NATION	TYPE	NOMINAL WT (LB)	ASSEMBLY DWG NO.	SPEC NO.	MODEL OF CANNON	PROJEC-TILE ASSEMBLY DWG NO.	COM-POSI-TION	WT (LB)	DWG NO.	KIND	WT (LB)	DWG NO.	METAL PARTS ASSEMBLY DWG NO.
1	STD	3416 5/	M581	APERS-T	41.25	9210603	PA-PD-2800 Ref	Rifle M40A1 M40A4	9210624	Flch Steel (8 grain) 6/	10.9	9210612 9211488	Tracer Proj M13	0.036	8860550	9210605
2	STD	36685 5/	M368	Dummy	37.93	8596153	FA-PD-MI 2380	Rifle M40A1 M40A1C M40A4	8596154	Inert	7.75	8596154	–	–	–	8596145
3	STD STD	37032 5/	M344A1 M344 3/	HEAT	36.19	7549097 75-1-319	MIL-C-13473	Rifle M40A1 M40A1C M40A4	7549096	Comp B	2.79	7549096	–	–	–	7549103
4	STD	37032 5/	M346A1	HEP-T	37.37	8837335	MIL-C-46250	Rifle M40A1 M40A1C M40A4	8837336	Comp A3	7.72	8837336	Tracer M5A2B1	0.10	8796866	8596145

1/ For M344A1
2/ For M344
3/ Fin Assembly, M8, Dwg. 7549111
4/ Inert Propellant loading omitted and Flash Tube replaced with built-up metal bar which provides the same weight and center of gravity as prototype.
5/ STD A for USMC use, AMCTC 7761.
6/ Expelling Charge M9, 1.23 oz, yellow dye 11 grams, Detonators (4) M86 (XM86) (1) XM87 with relay M7.

CHART 9. 106-MILLIMETER AMMUNITION

BODY			FUZE			PROPELLING ASSEMBLAGE								PERFORMANCE		PACKING	
BODY						CARTRIDGE CASE		PROPELLANT			PRIMER						
MATE-RIAL	MATE-RIAL FORM	DWG NO.	DESIG-NATION	TYPE	DWG NO	DESIG-NATION	DWG NO.	COM-POSI-TION	NOM WT (LB)	DWG NO.	DESIG-NATION	TYPE	DWG NO.	MAX RANGE (YD/M)	MV (fps/mps)	INNER PACK DWG NO.	OUTER PACK DWG NO.
Alum	Tubing Impact Extru.	9210607	M592	MT	10542850	M94B1	8596150	M26	8.0	9210603	M57	Perc	8838009	3,630 (3,319m)	1,440 (1,317 mps)	9212553	9212554
Steel	Plate	8596146	–	–	–	M94B1	8596150	4/	4/	–	–	Dummy	8596158	–	–	7549071	7549070
Steel	Tubing	7549077	M509A1	PIBD	8799735	M94B1 M93B1 1/ 2/	8596150 7548092	M26 M10 1/ 2/	8.06 8.10	7549097	M57	Perc	8838009	3,300 (3,017 m)	1,650 (1,509 mps)	7548962	7548963
Steel	Plate	8596146	M91A2	BD	8837308	M94B1	8596150	M26 M10 1/ 2/	9.0 8.04	8837335	M57	Perc	8838009	7,515 (6,872 m)	1,635 (1,995 mps)	7549071	7549070

CHART 10. 4.2-INCH MORTAR AMMUNITION

	CARTRIDGE								PROJECTILE							
										FILLER			COMPONENTS			
LINE NO.	TYPE CLASSI-FICA-TION	MSR. AMCTCM OR OTCM NO.	MODEL DESIG-NATION	TYPE	NOMINAL WT (LB)	ASSEMBLY DWG NO.	SPEC NO.	MODEL OF MORTAR	PROJEC-TILE ASSEMBLY DWG NO	COM-POSI-TION	WT (LB)	DWG NO.	KIND	WT (LB)	DWG NO.	METAL PARTS ASSEMBLY DWG NO.
1	STD OBS	36841 05776015	M2A1 M2	Agent Agent	24.91 24.91	75-1-284	MIL-S-13925 MIL-C-12476	Mortar Cannon M30 M2	75-14-630	H HT HD CNB CNS CK CG	6.20 5.75 6.00 5.75 To 8.00	75-14-630	10/ Case Proj Burster M14	0.73	10534914	1/ 75-2-420 2/ 75-2-422 3/ 75-2-443 4/ 75-2-445
2	OBS	11756003	M3A1 M3	HE	26.95 26.09	75-1-285	MIL-S-11354	Mortar Cannon M30	75-14-631	TNT	7.80	75-14-631	Suppl Chg TNT	0.365	8797090	5/ 75-2-427 6/ 75-2-429 7/ 75-2-441 8/ 75-2-442
3	STD	01756033	M329A2	HE	22.0	9235654	MIL-C-48087	M30 M2	9241269	Comp B	5.75	MIL-C-401 9241269	Suppl Chg	0.365	8797090	11738359
	STD CON STD	11756003 11756003 124	M329A1 M329 M329B1	HE HE HE	27.07 27.07 27.07	8863685 75-1-301 8863682	MIL-C-46983 MIL-C-46982	Mortar Cannon M30	8863929 75-14-643A 75-14-643B	TNT	7.80	8863929 75-14-643 75-14-643	Suppl Chg TNT	0.365	8797090	10523981 75-2-453 75-2-453
4	STD STD	3881 3881	M335A2 M335A1	Illum Illum	26.00 26.00	8886595 8833724	MIL-C-12926 MIL-C-12926	Mortar Cannon M30, M2	8886453 8833741	Illum Illum	3.31 3.31	8886446 8833772	Expel Chg BP	0.18 0.18	8886594 8833755	10534155 10521880

CHART 10. 4.2-INCH MORTAR AMMUNITION

BODY			OBTURATING MECHANISM		FUZE			PROPELLING ASSEMBLAGE					PERFORMANCE		PACKING	
								PROPELLANT			IGNITION CARTRIDGE					
MATERIAL	MATERIAL FORM	DWG NO.	DWG NO.	IGNITION CONTAINER EXTENSION	DESIGNATION	TYPE	DWG NO.	COMPOSITION	NOM WT (LB)	DWG NO.	DESIGNATION	DWG NO.	MAX RANGE (YD) yd (m)	MV (FPS) fps (mps)	INNER PACK DWG NO.	OUTER PACK DWG NO.
Steel	1/ Forg 2/ Tube 3/ Forg 4/ Tube	 75-2-421 75-2-426 75-2-534 75-2-534	1 75-2-426 2/ 75-2-426 3/ 75-2-534 4/ 75-2-534	 Without Without Without Without	M6	PD	72-2-311	M6 12/	0.60	71-12-27	M2	8797831	4961 4,460 m	879 255.8 mps	76-1-1189	76-1-1188
Steel	5/ Forg 6/ Tube 7/ Forg 8/ Tube	 75-2-428 75-2-430 75-2-426 75-2-430	5/ 75-2-426 6/ 75-2-426 7/ 8797834 8/ 8797834	 Without Without With With	M9 11 M557 M513 M564 M72· M732 M739	PD PD VT MTSQ PROX PROX PROX	73-2-312 8863535 1310500 10534285 11718400 11716451 9258620	M6	0.60	71-12-27	M2	8797831	5050 4,610 m	845 258 mps	7549247	7549246
Steel	Forg	9241269	11738362	With	15/M513 M739 M557 M564 15/M72· M732	PROX PD PD MTSQ PROX PROX	1310500 9258602 8863535 10534285 11718400 11716451			9252305	M2A2	9252205				
Steel	Tub/For Tube Forg	10523981 75-2-453A 75-2-453B	8863660 8797834	With	M557 M564 M513	PD MTSQ PROX	8863535 10534285 1310500	M36A1 M36 M36	0.60 0.60 0.60	8863617 8797836 8797836	M2A2 M2 M2	8882287 8797831	6180 5,660 m	981 299 mps	7549247	7549246
Steel Steel	Tube Tube	10534159 10521880	8863660 8797834	With With	M565 M562	MT MT	10522991 10520791	M36A1 M36A1	 0.60	8863617 8863617	M2A2 M2A1 M2	8882287 8863425	5962 5490 m 5290 m M335A1	1001 305.1 mps 301.9 mps	7549247 7549247	7549246 7549246

CHART 10. 4.2-INCH MORTAR AMMUNITION
(Continued)

CARTRIDGE									PROJECTILE							
										FILLER			COMPONENTS			
LINE NO.	TYPE CLASSI-FICA-TION	MSR, AMCTCM OR OTCM NO.	MODEL DESIG-NATION	TYPE	NOMINAL WT (LB)	ASSEMBLY DWG NO.	SPEC NO.	MODEL OF CANNON	PROJEC-TILE ASSEMBLY DWG NO.	COM-POSI-TION	WT (LB)	DWG NO.	KIND	WT (LB)	DWG NO.	METAL PARTS ASSEMBLY DWG NO.
1	STD	3416 5/	M581	APERS-T	41.25	9210603	PA-PD-2800 Ref	Rifle M40A1 M40A4	9210624	Flch Steel (8 grain) 6/	10.9	9210612 9211488	Tracer Proj M13	0.036	8860550	9210605
2	STD	36685 5/	M368	Dummy	37.93	8596153	FA-PD-MI 2380	Rifle M40A1 M40A1C M40A4	8596154	Inert	7.75	8596154	–	–	–	8596145
3	STD STD	37032 5/	M344A1 M344 3/	HEAT	36.19	7549097 75-1-319	MIL-C-13473	Rifle M40A1 M40A1C M40A4	7549096	Comp B	2.79	7549096	–	–	–	7549103
4	STD	37032 5/	M346A1	HEP-T	37.37	8837335	MIL-C-46250	Rifle M40A1 M40A1C M40A4	8837336	Comp A3	7.72	8837336	Tracer M5A2B1	0.10	8796866	8596145

1/ For M344A1
2/ For M344
3/ Fin Assembly, M8, Dwg. 7549111
4/ Inert Propellant loading omitted and Flash Tube replaced with built-up metal bar which provides the same weight and center of gravity as prototype.
5/ STD A for USMC use, AMCTC 7761.
6/ Expelling Charge M9, 1.23 oz, yellow dye 11 grams, Detonators (4) M86 (XM86) (1) XM87 with relay M7.

CHART 10. 4.2-INCH MORTAR AMMUNITION
(Continued)

BODY			OBTURATING MECHANISM		FUZE			PROPELLING ASSEMBLAGE: PROPELLANT			PROPELLING ASSEMBLAGE: IGNITION CARTRIDGE		PERFORMANCE		PACKING	
MATERIAL	MATERIAL FORM	DWG NO.	DWG NO.	IGNITION CONTAINER EXTENSION	DESIGNATION	TYPE	DWG NO.	COMPOSITION	NOM WT (LB)	DWG NO.	DESIGNATION	DWG NO.	MAX RANGE (YD) yd (m)	MV (FPS) fps (mps)	INNER PACK DWG NO.	OUTER PACK DWG NO.
Steel	1/ Forge 2/ Tube 3/ Forge 4/ Tube	 75-2-421 75-2-423 75-2-421 75-2-423	1/ 75-2-426 2/ 75-2-426 3/ 75-2-534 4/ 75-2-534	 -- -- Without Without	M8	PD	73-2-311	M6 12/	0.60	71-12-27	M2	8797831	5050 4,460 m	845 258.8 mps	76-1-1189	76-1-1188
Steel	1/ Forge 2/ Tube 3/ Forg 4/ Tube	 75-2-421 75-2-423 75-2-421 75-2-423	1/ 75-2-426 2/ 75-2-426 3/ 75-2-534 4/ 75-2-534	 Without Without	M8	PD	73-2-311	M6 12/	0.60	71-12-27	M2	8797831	5050 4,460 m	845 258.8 mps	76-1-1189	76-1-1188
Steel	Tube/ Forge	8797841	8863660	With	M521 M48A3 14/	PD PD	7549112 8798219	M36A1	0.06	8863617	M2A2	8882287	6180 5650 m	981 299 mps	7549247	7949248
Steel	Tube	8800090	8797834	With	M48A3 13/	PD	7549112	M36 12/	0.60	8797836	M2A1 M2	7521284 8797831	5931	960	7549247	7549248
Steel	Tube	10534159	8863660	With	M548 M565	MTSQ MT	10526638 10522991	M36A1	0.60	8863617	M2A2	8882287	6180 5650 m	981 299 mps	7549247	7549248

CHART 11. 120-MILLIMETER AMMUNITION

										PROJECTILE							
										FILLER		COMPONENTS				BODY	
LINE NO.	TYPE CLASSI-FICA-TION	MSR. AMCTCM OR OTCM NO	MODEL DESIG-NATION	TYPE	NOMINAL WT (LB)	ASSEMBLY DWG NO.	SPEC NO	MODEL OF CANNON	LOADING ASSEMBLY DWG NO	COM-POSI-TION	WT (LB)	KIND	WT (LB)	DWG NO.	METAL PARTS ASSEMBLY DWG NO	MATE-RIAL	MATE-RIAL FORM
1	STD	36841	M358	AP-T	50.85	7548465	OAC-PD-96	Tank Gun M58	7548465	—	—	Tracer M5 Series	0.10	8796866	8593352	Steel & Alumi-num	Forged
2	STD	38009	M469	HEAT-T	31.11	8840529	MIL-P-46251	Tank Gun M58	8840529	Comp B	4.5	Tracer Proj M13 Series	0.036	8860550	8595213	Steel	—
3	STD	38841	M356	HE-T	50.41	8822495	MIL-P-46925	Tank Gun M58	8822494	Comp B	7.84	Tracer M5 Series	0.10	882253	1052346	Steel	Forged
4	STD	37741	M357	Smoke WP-T	50.41	8826685	MIL-S-20601	Tank Gun M58	8826690	WP	7.5	Tracer M7	0.10	8822553	10523470	Steel	Forged
5	STD	36841	M359	TP-T	50.93	7548465	OAC-PD-96	Tank Gun M58	7548466	—	—	Tracer M5A2B1	0.10	8796866	8593614	Steel	Forged

CHART 11A. 120-MILLIMETER A

									CARTRIDGE								
									FILLER			COMPONENTS			BODY		
LINE NO.	TYPE CLASSI-FICA-TION	MSR AMCTCM OR OTCM NO	MODEL DESIG-NATION	TYPE	NOMINAL WEIGHT (LBS)	ASSEMBLY DWG NO	SPEC. NO	MODEL OF CANNON	COMPO-SITION	DWG NO	METAL PARTS DWG NO	KIND	WT (LB)	DWG NO	MATE-RIAL	MATE-RIAL FORM	DWG NO
1	LP	DA Ltr 3/83	XM827	APFSDS-T	42.0	12524901	DOD-C-63482 (LAP) DOD-C-63483 (MPTS)	XM256	Depleted Uranium (Penetrator) Aluminum (Sabot)	12524900	12524965	— Tracer M13	— 0.036	— 8860550	—	—	—
2	STD	08856009	M831	TP-T	30.0	12527126	DOD-C-63480	XM256	Steel, Forged	12527102	12527137	Tracer M13	0.036	8860550	Steel	4140	12527128
3	STD	08856005	M865	TPCSDS-T	41.0	12525000	DOD-P-64010	XM256	Steel	12527103	DOD-P-64009	Tracer M13	0.036	8860550	Steel	4140	12575002
4	STD	08856006	M829	APFSDS-T	41.0	12525600	DOD-6-64013 ANSI Y 14.5 -1973	XM256	Depleted Uranium Penetrator Alum. Sabot	—	12525601	2/ Tracer M13	0.036	8860550	—	Forged	12525601
5	STD	08856007	M830	HEAT-MP-T	53.0	12526622	DOD-C-63486 DOD-C-63488	M256	Comp A3 Type 2	12520618	—	Tracer M13	0.036	8860550	Steel	4140	12526654

1/ Cartridge case is steel base/combustible side wall
2/ Fuze - Model M764, Type PIBD, Dwg. No. 12528700

CHART 11. 120-MILLIMETER AMMUNITION

	FUZE			PROPELLING ASSEMBLAGE									PERFORMANCE		PACKING		
				PROPELLING CHARGE ASSEMBLY		CARTRIDGE CASE		PROPELLANT		PRIMER					PROPELLING CHARGE ASSEMBLY	PROJECTILE	
DWG NO.	DESIG-NATION	TYPE	DWG NO.	DESIG-NATION	DWG NO.	DESIG-NATION	DWG NO	DESIG-NATION	NOM WT (LB)	DESIG-NATION & TYPE	DWG NO.	MAX RANGE (YD/M)	MV (fps/mps)	DWG NO.	INNER PACK DWG NO.	OUTER PACK DWG NO.
8593350	–	–	–	M46 (T38E1)	7548559	M109	7548022	M17	29.0	M67 Perc-Elec	7548520	25,290 (23,125 m)	3,500 (1,067 mps)	7548593	7548595	7548596
8595218	M509A1	PIBD	8799735	M99 (T42E1)	8840528	M111	8593161	M6	22	M96 Perc	8837988	25,290 (23,125 m)	3,750 (1,143 mps)	8800073	8800074	8800072
10523462	M557	PD	8863535	M45 (T21E1)	8822490	M109 (T25) (Brass)	7548022	M31	12.4	M67 Perc-Elec	7548520	19,910 (18,206 m)	2,500 (762 mps)	7548593	7548597	7548596
10523470	M557	PD	8863535	M45 (T21E1)	8822490	M109 (T25)	7548022	M31	12.4	M67 Perc Elec (T85E3)	7548520	19,910 (18,206 m)	2,500 (762 mps)	7548593	7548597	7548596
8593612	–	–	–	M46	7548599	M109	7548022	M17	29.0	M67 Perc-Elec	7548520	25,290 (23,125 m)	3,500 (1,067 mps)	7548583	7548597	7548596

FUZE			PROPELLING CHARGE ASSEMBLY		PROPELLING ASSEMBLAGE											
					CARTRIDGE CASE		PROPELLANT			PRIMER			PERFORMANCE		PACKING	
DESIG-NATION	TYPE	DWG. NO	DESIG-NATION	DWG NO.	DESIG-NATION	DWG. NO.	COMPO-SITION	NOM WT (LB)	SPEC DWG NO.	MODEL	TYPE	DWG. NO.	MAX RANGE	MV	INNER PACK DWG NO.	OUTER PACK DWG NO.
N/A	–	–	–	–	1	12524976	JA2 granular	16.0	DOD-P-63493	XM124	Elec	12524974	3000 meters	1600 m/s 5404 f/s	12527260	12527240
N/A	–	–	–	–	1	12524833	DIGL-RP FORM A	27	DOD-P-63492	XM123	Elec	12526327		1140 mps 3740 fps	12527260	12527240
N/A	–	–	–	–	1	12524976	LKL	17.0	DOD-P-64039	XM124	Elec	12524974	7500 meters 8206 yards	1700 m/s 5576 f/s	12527260	12527240
N/A	–	–	JA2	DOD-P-64035	1	12524938 CASE BASE 12524833	JA2	17.8	DOD-P-64035	M125	Elec	12525016	–	–	9354465 9354483	12527240
M764	PIBD 2	12526700	–	12526256	–	12526679 CASE BASE 12524934	DIGL-RP FORM A	7.7 (395 Kg)	DOD-P-63492	XM123	Elec	12526327	–	–	12527220 12527260	12527240

CHART 12. 152-MILLIMETER AMMUNITION

CARTRIDGE									PROJECTILE							
										FILLER			COMPONENTS			
LINE NO.	TYPE CLASSI-FICA-TION	MSR, AMCTCM OR OTCM NO.	MODEL DESIG-NATION	TYPE	NOMINAL WT (LB)	ASSEMBLY DWG NO.	SPEC NO.	MODEL OF CANNON	PROJECTILE ASSEMBLY DWG NO.	COMPOSI-TION	WT (LB)	DWG NO.	KIND	WT (LB)	DWG NO.	METAL PARTS ASSEMBLY DWG NO.
1	STD CON	3966 11756003	M625A1 M625	CTSR	48.5	9252590 9215469	MIL-C-50912 PA-PD-2919	M81 Series M162	9221155	Flch gr Steel	15.2	9219980	--	--	--	9221155
2	STD	5909	M596	Dummy	51.0	8430306	MIL-C-60830	M81	8430306	--	--	--	--	--	--	8430306
3	CON	9193	M657	HE-T	51.5	9223763	MIL-C-48094 PA-PD-3057	M81	9223764	TNT	9.5		Tracer M13	0.033	8860550	9223765
4	STD CON	8965	M409A1 M409	HEAT-T-MP	48.5	9204196	MIL-C-50846 PA-PD-2608	M81 Series M162	9204197	Comp B	6.3	MIL-C-401	Tracer M13	0.033	8860550	10534407 9209390
5	STD	DA Ltr	M409A2	HEAT-T MP	50.5	9323962	MIL-C-63250	M81 M162	9323963	Comp B	6.3	MIL-C-401	Tracer M13	0.033	8860550	10534407
6	CON	9103	M411 (XM411E3)	TP-T	48.8	9210425	MIL-C-600-60	M81 M162	9210426	Sup Chg TNT	[illegible].3	8797090	Tracer	0.033	8860550	10534387
7	CON	9103	M411A1 (XM411E4)	TP-T	49.8	9233376	MIL-C-600-60	M81 M162	9233375	--	--	--	Tracer	0.033	8860550	10534387
8	STD	9103	M411A2 (XM411E5)	TP-T	49.6	9242430	MIL-C-50530	M81 M162	9210436	--	--	--	Tracer M13	0.033	8860550	10551338
9	STD	9103	M411A3 (XM411E7)	TP-T	46.8	9266944	MIL-C-50902	M81 M162	10551938	--	--	--	Tracer M13	0.033	8860550	10551338

1/ Primer consists of ignition element electrical DWG NO. 9249028; Ignition assembly DWG NO. 9212218; Tube, DWG NO. 9204182-1 and Plug Closing, DWG NO. 9204177.

CHART 12. 152-MILLIMETER AMMUNITION

BODY			FUZE			PROPELLING ASSEMBLAGE								PERFORMANCE		PACKING	
						CARTRIDGE CASE		PROPELLANT			PRIMER						
MATERIAL	MATERIAL FORM	DWG NO.	DESIGNATION	TYPE	DWG NO.	DESIGNATION	DWG NO.	COMPOSITION	NOM WT (LB)	DWG NO.	DESIGNATION	TYPE	DWG NO.	MAX RANGE vd (m)	MV fps (mps)	INNER PACK DWG NO.	OUTER PACK DWG NO.
Alum	Tube or Forg	9221154	--	--	--	M205 M157	9252619 9227746	M26E1 M189	6.0	9207817	1/ M91	Elec	1/ 9204038	440 400 m	2260	9221407	9221408
Alum	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	8880419	9229158
Steel	Forg	9223765	M720	PD	9229636	M157	9227746	M26E1	6.0	9207817	M117	Elec	9233541	4376 9000 m	2240	9224908	9224909
Steel	Forg	10534409	M539	PIBD	9212208	M205 M157	9252619 9227746	M26E1	6.0	9207817	M91	Elec	9249028	9000 m	2240	9260120	9212118
Steel	Forg	10534408	M539A1	PIBD	9212208	M205	9252619	M26	6.0	PA-PD-2615	M91	Elec	9249038	--	2240	9246417	9271646
Steel	Forg	10534388	M557	PD	8863535	M157	9227746	M26E1	6.0	9207817	M91	Elec	9249038	9000 m	2240	9260120	9212118
Steel	Forg	10534328	--	--	--	M157	9227746	M26E1	6.0	9207817	M91	Elec	9249038	9000 m	2240	9260120	9212118
Steel	Forg	10551940	--	--	--	M157	9227746	M26E1	6.0	9207817	M91	Elec	9249038	9000 m	2240	9260120	9212118
Steel	Forg	10551940	--	--	--	M205	9252619	M26E1	6.0	9207817	N/A	Elec	9249028	9000 m	2240	9260120	9212118

CHART 13. 155-MILLIMETER AMMUNITION

										PROJECTILE						
										FILLER			COMPONENTS			
LINE NO.	TYPE-CLASSIFICATION	MSR, AMCTCM OR OTCM NO.	MODEL DESIGNATION	TYPE	NOMINAL WT (LB)	ASSEMBLY DWG NO.	SPEC NO.	MODEL OF CANNON	PROJECTILE ASSEMBLY NO.	COMPOSITION	WT (LB)	DWG NO.	KIND	WT (LB)	DWG NO.	METAL PARTS ASSEMBLY DWG NO.
1	STD	36841	M104	Agent	94.6	75-14-296	MIL-S-12846	Gun M2 M2A1 M46	75-14-298	HD Pers	11.70	75-14-296	Burster M6 Tetrytol 2	0.83	9210893	75-4-89
2	STD	36841	M110	Agent	98.49	75-14-317	MIL-S-12846	How M1 M1A1 M1A2 M45 M126 M126A1 M185 M199	75-14-317	H HD Pers	11.70	75-14-317	Burster M6 Tetrytol 2	0.83	9210893	75-4-207
3	STD STD	37870	M121A1 M121	Agent	98.9	8861029	MIL-P-46412	How M1 M1A1 M45 M126 M126A1 M185 M199	8861031	VX Pers	6.30	8861031	Burster Proj M71 Comp B-4 Suppl Chg 1	2.45 0.367	8861032 8797090	7548847
4	STD STD	37870	M121A1 M121	Agent	99.70	8861029	MIL-P-46412	How M1 M1A1 M1A2 M45 M126 M185 M199	8861030	GB Non- Pers	6.5	8861030	Burster Proj M71 Comp B-4 1	2.45 0.367	8861032 8797090	7548847
5	STD	36841	M122	Agent	100.1	9241805	MIL-S-12846	Gun M2 M2A1 M46	9241804	GB Non- Pers	6.5	9241805	Burster M37 Tetrytol M2 Suppl Chg 1	2.72 0.367	73-1-264 8861035 8797090	75-4-206
6	STD	02786003	M718	AT	103	9277852-2 (LAP)	MIL-P-63238	How M1A2 M126 M185 M199	9278076 (MTL PTS)	PBX 0280	1.26 per unit	9278018	Expel Chg Assy (M10 Propellant)	0.112	9272019	9282845
7	STD	01786003	M741	AT	103	9278014-2 (LAP)	MIL-P-63238	How M1A2 M126 M185 M199	9278076 (MTL PTS)	PBX 0280	1.26 per unit	9278018	Expel Chg Assy (M10 Propellant)	0.112	9272019	9282848
8	OBS	37119	MK1	Dummy	95.0	72-1-28	—	How M126 M1 M1A1 M45	—	—	—	—	—	—	—	—

CHART 13. 155-MILLIMETER AMMUNITION

MUNITION

BODY			FUZE			PROPELLING ASSEMBLAGE						PERFORMANCE		PACKING	
						PROPELLING CHARGE		PROPELLANT			PRIMER				
MATERIAL	MATERIAL FORM	DWG NO.	MODEL	TYPE	DWG NO	MOL	DWG NO.	DESIGNATION	NOM WT (LB)	DWG NO.		MAX RANGE yd (m)	MV fps (mps)	PROPELLING CHARGE ASSEMBLY DWG NO.	PROJECTILE DWG NO.
Steel	Forged	75-4-100	M557 M739	PD PD	8863535 9258602	M19 M19A	71-9-94 9226436	M6 M6	31	71-9-94	9/ 10/	NC 18605 SC 25715	NC 2100 SC 2800	7548187	7549274
Steel	Forged	75-4-100	M557 M739 M564	PD PD MTSQ	8863535 9258602 10534285	M3 M4A1 M119 M119A M119A2	8864405 71-9-180 9226436 9325852 9333954	M1 M1 M6 M6 M6	5 13.5 20.5 20.5 20.9	8864406 71-9-180 71-9-269	9/ 10/ 15/	12/ 12/	12/ 12/	7548187 9234357	7549274
Steel	Forged	7548846	M739 M557 M728 4/ M732	PD PD PROX PROX	9258602 8863535 11719400 11716451	M3 M4A1 M119 M119A1 M119A2	8864405 71-9-180 9226436 9325852 9333954	M1 M1 M6 M6 M6	5 13.5 20.5 20.5 20.9	8864406 71-9-180	9/ 10/ 15/	12/ 12/	12/ 12/	7548187 9234357	7549274
Steel	Forged	7548846	M739 M728 4/ M557 M732	PD PROX PD PROX	9258602 11718400 8863535 11716451	M3 Series M119 M119A1 M119A2	8864405 71-9-180 9226436 9325852 9333954	M1 M1 M6 M6 M6	5 13.5 20.5 20.5 20.9	8864406 75-9-180	9/ 10/ 15/	12/ 12/	12/ 12/	7548187 9234357	7549274 7549275
Steel	Forged	75-4-206	M557 M728 M739	PD VT PD	7549041 11718400 9258602	M19 20/	71-9-94	M6	31	71-9-94	9/ 10/	NC 18605 SC 25715	NC 2100 SC 2800	7548187	7549274
Steel	Forged	9277860 9278078	M577	MTSQ	9236500	M3A1 M4A2 M119 M119A1	8887277 9207624 9226436 9325852	M1 M1 M6 M6	5.0 13.5 20.5 20.5	8864406 71-9-180 71-9-269	M82 M82 M82	17,500 m	650 mps	9234357	9317586 8/pallet
Steel	Forged	9277860 9278078	M577	MTSQ	9236500	M3A1 M4A2 M119 M119A1	8887277 9207624 9226436 9325852	M1 M1 M6 M6	5.0 13.5 20.5 20.5	8864406 71-9-180 71-9-269	M82 M82 M82	17,500 m	650.5 mps	9234357	9317586 8/pallet
Iron	Cast	72-1-28	1907M 17/	Inert	73-3-47	Dummy M2	72-2-54	–	7.37	–	11/	–	–	–	76-3-9

CHART 13. 155-MILLIMETER AMMUNITION
(Continued)

									PROJECTILE							
										FILLER			COMPONENTS			
LINE NO.	TYPE-CLASSI-FICA-TION	MSR, AMCTCM OR OTCM NO.	MODEL DESIG-NATION	TYPE	NOMINAL WT (LB)	ASSEMBLY DWG NO.	SPEC NO.	MODEL OF CANNON	PROJEC-TILE ASSEMBLY NO.	COM-POSI-TION	WT (LB)	DWG NO.	KIND	WT (LB)	DWG NO.	METAL PARTS ASSEMBLY DWG NO.
9	STD	36841	M7	Dummy	95.	72-1-69	—	How M126 M126A1 M1 M1A1 M45 Gun M2 M2A1 M46	—	—	—	—	—	—	—	—
10	STD	36841	M101 (deep cavity)	HE	95.10	75-14-692	MIL-L-0020336 MIL-L-20336	Gun M2 M2A1 M46	—	TNT	14.61	75-14-692	Suppl Chg	0.365	8797090	75-4-80
11	STD	36841	M101 (normal cavity) 7/	HE	95.73	75-14-616	MIL-L-0020336 MIL-L-20336	Gun M2 M2A1 M46	—	TNT	15.48	75-14-616	—	—	—	75-4-80
12	STD	36841	M107 (normal cavity)	HE	95.6	9216352	MIL-P-60377	How M126 M1 M1A1 M1A2 M45 M185	9216352-1 9216352-2	Comp B TNT	15.4 14.6	9216352-1 9216352-2	—	—	—	10535925
13	STD	36841	M107 (deep cavity)	HE	95.6	9216352	MIL-P-60377	How M1 M1A1 M1A2 M45 M126 M185 M199	9216352-1 9216352-2	Comp B TNT	15.4 14.6	9216352-1 9216352-2	Suppl Chg	0.367	8797090	10535925
14	OBS	11756003	M107B2 5/ 16/	HE	95.6	9210072	PA-PD-2742	How M1 M1A1 M45 Gun M2 M2A1 M46	75-14-692 75-14-616	TNT	14.61 15.48	75-14-692 6/ 75-14-616 6/	Suppl Chg	0.367	8797090	75-4-80
15	STD	3982	M449A1 M449 M449E1	HE	95	P133519 8875850 8875849	MIL-P-50538	How M1 M1A1 M1A2 M45 M126 M126A1 M199	P133519 8875850 8875849	Comp A5	2.8	MIL-E-14970	60 M43A1 Gren Expel Chg (M10 Propellant)	0.066	8875900 8875860	8875855

CHART 13. 155-MILLIMETER AMMUNITION
(Continued)

BODY			FUZE			PROPELLING ASSEMBLAGE						PERFORMANCE		PACKING	
						PROPELLING CHARGE		PROPELLANT			PRIMER				
MATE-RIAL	MATE-RIAL FORM	DWG NO.	MODEL	TYPE	DWG NO	MODEL	DWG NO.	DESIG-NATION	NOM WT (LB)	DWG NO.		MAX RANGE yd (m)	MV fps (mps)	PROPELLING CHARGE ASSEMBLY DWG NO.	PROJECTILE DWG NO.
Steel	Cast	72-1-70	None	–	–	Dummy M2 Dummy M100 20/	72-2-54 72-2-28	–	7.37 32.20	–	11/	–	–	–	76-3-9
Steel	Forged	75-4-80	M557 M728	PD PROX VT	8863535 11718400	M19 20/	71-9-94	M6 M6	31	71-9-94	9/ 10/	NC 18605 SC 25715	NC 2100 SC 2800	7548187	7549274
Steel	Forged	75-4-80	M557	PD	8863535	M19 20/	71-9-94	M6	31	71-9-94	9/ 10/	NC 18605 SC 25715	NC 2100 SC 2800	7548187	7549274
Steel	Forged	10535927	M739 M557 M564 M732 M582	PD PD MTSQ PROX MTSQ	9258602 8863535 10534285 11716451 9236701	M3 M4A1 M119 M119A1 M119A2	8864405 71-9-180 71-9-94 9226436 9325852 9333954	M1 M1 M6 M6 M6 M6	5 13.5 20.5 20.5 20.5 20.9	8864406 71-9-180 71-9-94 71-9-269 71-9-269	9/ 10/ 15/	12/ 12/	12/ 12/	7548187 9234357	7549275
Steel	Forged	10535927	M739 M557 M564 M728 4/ M732 M582	PD PD MTSQ PROX VT PROX MTSQ	9258602 8863535 10534285 11718400 11716451 9236701	M3 M4A1 M3A1 M4A2 M119 M119A1 M119A2	8864405 71-9-180 8887277 9207624 9226436 9325852 9333954	M1 M1 M6 M6	5 13.5 31 20.9	8864406 71-9-180 71-9-94	9/ 10/ 15/	12/ 12/	12/ 12/	7548187 9234357	7549275
Steel	Forged	75-4-80	M557	PD	8863535	M3 M4A1 M19 3/ 20/	8864405 71-9-180 71-9-94	M1 M1 M6	5 13.5 31	8864406 71-9-180 71-9-94	9/ 10/ 15/	12/ 12/	12/ 12/	7548187	7549274
Steel	Forged	8875856	M548 M565 M577	MTSQ MT MTSQ	8864933 10522991 9236500	M3 M3A1 M4 M4A1 M4A2 M119 M119A1 M119A2	8864405 8887277 71-9-180 71-9-180 9207624 9226436 9325852 9333954	M1 M1 M1 M1 M1 M6 M6 M6	5 5 13.5 13.5 13.5 20.5 20.5 20.9	8864406 8887277 71-9-180 71-9-180 9207624 71-9-269 71-9-269	9/ 10/ 15/	13/ 12/	1850	7548187 9234357	7549275

CHART 13. 155-MILLIMETER AMMUNITION
(Continued)

									PROJECTILE							
										FILLER			COMPONENTS			
LINE NO.	TYPE-CLASSI-FICA-TION	MSR, AMCTCM OR OTCM NO.	MODEL DESIG-NATION	TYPE	NOMINAL WT (LB)	ASSEMBLY DWG NO.	SPEC NO.	MODEL OF CANNON	PROJEC-TILE ASSEMBLY NO.	COM-POSI-TION	WT (LB)	DWG NO.	KIND	WT (LB)	DWG NO.	METAL PARTS ASSEMBLY DWG NO.
16	STD	10756043	M483A1	HE	102.6	9215220	MIL-P-48749	How M126 M185 M199 M1A2	9215220	Comp A-5	6.25	MIL-E-14970	M42 Gren M46 Gren Expel Chg Assy (M10 Pro-pellant)	– – 0.112	9215340 9215370 9272019	10542902
17	STD	8753	M549 M549A1	HE RA	96.0	9235999 9235999-1	MIL-P-50578	M126 M126A1 M185 M1A2 M199	9235998	Comp B TNT	16.0 15.0	9235999	Suppl Chg	0.367	8097090	9235995
18	STD	01766104	M692	HE	102.5	9298315	MIL-P-48187	How M1A2 M126 M185 M199	9298350	Comp A-5	1.69	MIL-E-14970	Expel Chg (M10 Pro-pellant) 36 AP Mines	0.112	9298360	9298350
19	STD	01766014	M731	HE	102.5	9298316	MIL-P-48187	How M1A2 M126 M185 M199	9298350	Comp A-5	1.69	MIL-E-14970	Expel Chg Assy (M10 Propellant) 36 AP Mines	0.112	9298360	9298350
20	STD	11796005	M712	HEAT	138.0	9305300	MIL-P-63223	How M185 M199	9307011	Comp B	14.75	MIL-C-401 GP				9305300
21	OBS	11756003 04808009	M118A2 M118 M118A1	Illum	102.0	75-14-480	OAC-PD-140	How M126 M1 M1A1 M1A2 M45 Gun 3/ M2 M2A1 M46	75-1-679	Illum	4.30	75-194679	Cnge Ejection 1st	0.118	75-4-201	75-4-120
22	STD STD C8T	7468	M485A2 M485A1 M485 Series	Illum	92.0	9214150	PA-PD-2823	How M1 M1A1 M45 M126 M185 M199	9213758	Illum	5.8	9213716	Expel Chg 1st Ld Expel Chg 2d Ld Cng Eject 1st Fire	0.22 0.17 0.2	9213716	9214142
23	STD	36841	M104	Smoke	89.02	75-14-296	MIL-S-12846	Gun M2 M2A1 M46	75	WP	15.60	75-14-296	Burster M6 Tetrytol 2/	0.83	9210893	75-4-89

CHART 13. 155-MILLIMETER AMMUNITION
(Continued)

	BODY			FUZE			PROPELLING ASSEMBLAGE						PERFORMANCE		PACKING	
							PROPELLING CHARGE		PROPELLANT			PRIMER				
Y	MATERIAL	MATERIAL FORM	DWG NO.	MODEL	TYPE	DWG NO	MODEL	DWG NO.	DESIGNATION	NOM WT (LB)	DWG NO.		MAX RANGE yd (m)	MV fps (mps)	PROPELLING CHARGE ASSEMBLY DWG NO.	PROJECTILE DWG NO.
	Steel	Forged	10542902	M577	MTSQ	9236500	M3 M4A2 M119 M119A1 M119A2	8864405 9207624 9226436 9325852 9333954	M1 M1 M6 M6 M6	5.0 13.5 20.5 20.5 20.9	8864406 71-9-180 71-9-269 71-9-269	9/ 10/ 15/	9330 m 14,320 m 22,400 m 17,740 m 17,740 m	358.3 mps 535.2 mps 797 mps 655.8 mps 855.8 mps	7548187 9234357 9293303 9234357 9234357	8837839
	Steel	Forged	9236003	M739 M557 M587	PD PD MTSQ	9258602 8863535 9236701	M4A2 M119A1 M203/A1 18/ M119A2	9207624 9325852 9281897 9345103 9333954	M1 + .01 Potassium Sulfate M6	5.5 13.12 26.0 20.9	8887277 9207624	9/ 10/ 15/	–	–	7548189 9234357	8837839
	Steel	Forged	9298354	M577 M724	MTSQ	9236500 117112(	M3A1 M4A2 M119 M119A1 M119A2	8887277 9207624 9226436 9325852 9333954	M1 M1 M6 M6 M6	5.0 13.5 20.5 20.5 20.9	8887277 71-9-180 71-9-269 71-9-269	9/ 10/ 15/	14,586 m 16,044 m	560.2 mps 563.5 mps	7548187 9234357	8837839
	Steel	Forged	9298354	M577 :4	MTSQ	9236500	M3A1 M4A2 M119 M119A1 M119A2	8887277 9207624 9226436 9325852 9333954	M1 M1 M6 M6 M6	5.0 13.5 20.5 20.5 20.9	8864406 71-9-180 71-9-269 71-9-269	9/ 10/ 15/	14,586 m 16,044 m	560.2 mps 563.5 mps	7548187 9234357	8837839
	Steel	Forged	9307001	M740 (integral to proj)	PIBD	9307466	M3A1 M4A2 M119 21/ M119A1 M119A2	8887277 9207624 9226436 9325852 9333954	M1 M1 M6 M6 M6	5.0 13.5 20.5 20.5 20.9	8864406 71-9-180 71-9-269 71-9-269	M82	–	–	7548187 9234357	9305425 9305435
	Steel	Forged Tube (M118-A2B1)	75-4-121	M501	MTSQ	8797484	M3 M4A1 M19 3/ 20/	8864405 71-9-180 71-9-94	M1 M1 M6	5.0 13.5 31.0	8864406 71-9-180 71-9-94	9/ 10/ 15/	14,400 m 3/ 12,680 m 13/	2000 mps 3/ 1760 mps 13/	7548187	7549274
	Steel	Forged	9214143	M565 M577	MT MTSQ	10522991 9236500	M3 M3A1 M4A1 M4A2 M119 21/ M119A1 M119A2	8864405 8887277 71-9-180 9207624 9226436 9325852 9333954	M1 M1 M1 M1 M6 M6 M6	5.0 5.0 13.5 13.5 20.5 20.5 20.9	8864406 8887277 71-9-180 9207624	M82 MK2A4	15,400 m	1850 mps	7548187	7549275
	Steel	Forged	75-20-80	M557	PD	8863535	M19 20/	71-9-94	M6	31.0	71-9-94	9/ 10/	NC 18605 SC 25715	NC 2100 SC 2800	7548187	7549274

CHART 13. 155-MILLIMETER AMMUNITION (Continued)

LINE NO.	TYPE-CLASSI-FICA-TION	MSR, AMCTCM OR OTCM NO.	MODEL DESIG-NATION	TYPE	NOMINAL WT (LB)	ASSEMBLY DWG NO.	SPEC NO.	MODEL OF CANNON	PROJECTILE: PROJEC-TILE ASSEMBLY NO.	FILLER: COM-POSI-TION	FILLER: WT (LB)	FILLER: DWG NO.	COMPONENTS: KIND	COMPONENTS: WT (LB)	COMPONENTS: DWG NO.	METAL PARTS ASSEMBLY DWG NO.	
24	OBS	6558	M105	Smoke	98.2	75-14-293	MIL-S-12846	How M1 M1A1 M45 M126	–	WP	15.60	75-14-293	Burster M6 Tetrytol 2/	0.83	9210893	75-4-90	
25	STD	9019	M110 M10A1 M10A2 8/	Smoke	98.49	75-14-317 9210424 9217030 8/	MIL-S-12846 PA-PD-2744	How M1 M1A1 M45 M126 Gun M2 M2A1 M46 M126 M185 M199	75-14-296 9217031	WP WP	15.60 15.06	75-14-317 9217030 75-14-296 9217030	Burster M6 Tetrytol 2/ Burster M54 M54A1 Comp B	0.83 0.9 1.3	9210893 9223427 9238839	75-4-207 75-4-89 8/ 10592945	
26	STD OBS STD	36841 11756003 04786002	M116 (HC & Rem Clrs) M116 (Violet only) M116A1	Smoke	94.80 (HC) 88.23 (Clrd) 86.23	8885162-1 (orig to rev) 8885162-25 8885162 Rev D	MIL-P-20512 MIL-P-20512C	How M126 M1 M1A1 M45 Gun 3/ M2 M2A1 M46 How M1A1 M1A2 M185 M199	C15-11-33 (HC) C15-11-65 (Clrd) C15-11-33 C15-11-41	HC Clrd HC	25.84 17.19	C15-11-33 (HC) C15-11-65 (Clrd) C15-11-33 C15-11-41	Expel Chg Assy Expel Chg Assy	0.29 0.34	9207695	10534904	
27	STD	11796005	M823 19/	Training	137.0	9329721	–	M185 M199	–	Inert	–	–	–	–	–	9329721	
28	STD	01816002	M804	Practice	95.0	9331794	MIL-P-63345	M1A2 M126A1 M185 M199	–	Inert	–	–	Smk Charge	52 9 ms	9333792	9331795	S
29	STD LCC-A	01876014	M825	Smoke	102.6	E15-12-259	MIL-P-64007	M1A2 M126A1 M185 M199	E15-12-289	WP	12.75	MIL-C-215	Expel Chg (M10 Pro-pellant) Burster Comp A5	0.117 0.75	D15-12-316 D15-12-272	9352634	S
30	STD	97856004	M795	HE	103.4	9312769	DOD-P 63252	M1A2 M126 M185 M199	9312769	TNT	23.8	9342881	SUP Charge	0.367	5797090	9326055	

1/ Case, Projectile, Burster, M15, Dwg. 10521645 is used.
2/ Casing, Burster, M1 Dwg 73-1-168 is used.
3/ Authorized for use with gun with normal charge only.
4/ Supplementary charge removed.
5/ Conversion of Projectile 155MM, HE, M101, Gun.
6/ With supplementary charge.
7/ Without supplementary charge.
8/ Conversion of Projectile 155MM, Smoke, WP, M104, Gun.
9/ Primer, Percussion, MK 2A4, Dwg. 3840362, for How M1 & M1A1 and Gun M2 & M2A1.
10/ Primer, Percussion-Electric, MK 15 Mod 1, Dwg 74-8-5, and Primer, Electric, MK 34 Mod 0, Dwg 439166, for How M45 and Gun M46.
11/ Primer, Percussion (Inert), MK 2A4, Dwg 3840362.
12/

	Zone 5	Zone 7
Max Range Yards	10820	15958
Muzzle Velocity, FPS	1230	1840

M3 Charge, Zones 1-5; M4A1 Charge, Zones 3-7. Flash Reducer M2 used with M4A1 Propelling Charge for night firing
Flash Reducer M1 used with M19 Propelling Charge.

CHART 13. 155-MILLIMETER AMMUNITION
(Continued)

BODY			FUZE			PROPELLING ASSEMBLAGE						PERFORMANCE		PACKING	
						PROPELLING CHARGE		PROPELLANT			PRIMER				
MATE-RIAL	MATE-RIAL FORM	DWG NO.	MODEL	TYPE	DWG NO.	MODEL	DWG NO.	DESIG-NATION	NOM WT (LB)	DWG NO.	–	MAX RANGE yd (m)	MV fps (mps)	PROPELLING CHARGE ASSEMBLY DWG NO.	PROJECTILE DWG NO.
Steel	Forged	75-20-80	M557	PD	8863535	M3	8864405	M1	5.0	8864406	9/ 10/	14/	14/	7548187	7549274
Steel	Forged	75-4-100 75-4-80 3/ 10592945	M739 M557 M564 M582	PD PD MTSQ MTSQ	9258602 8863535 10534285 9236701	M3 M4A1 3/ M19 20/ M3A1 M4A2 M119 M119A1 M119A2	8864405 71-9-180 71-9-94 8882277 9207624 9226436 9325852 9333954	M1 M1 M6 M1 M6 M6 M6 M6	5.0 13.5 31 5.5 13.5 20.5 20.5 20.9	8864406 71-9-180 71-9-94 8887277 9207624	9/ 10/ 15/ M1	12/ 12/	12/ 12/	7548187 9234357	9549274 7549275
Steel Steel	Forged Forged	10534905	M501 M565 M577	MTSQ MT MTSQ	9797484 10522991 9236500	M3 M4A1 M19 20/ M119 M119A1 3/ M119A2	8864405 71-9-180 71-9-94 9226436 9325852 9333954	M1 M1 M6 M6	5.0 13.5 31.0 20.9	8864406 71-9-180 71-9-94	9/ 10/ 15/ -	12/ 12/	13/ 13/	7548187 9234357	7549274
Alum	–	9331160	N/A	–	–	N/A	–	–	–	–	N/A	N/A	–	–	9305335
Steel	Forged	9331298	M557 M739 M564 M582	PD PD MTSQ MTSQ	8863535 9258602 10534285 9236701	M3A1 M4A2 22/	8882277 9207624	M1 M6	5.5 20.5 13.5	8882277 9207624	9/ 18/	–	–	7548187	7549274
Steel	Forged	9352632	M577	MT	9236500	M3 M4Series M119 M119A1 M119A2 M203 23/ M203A1	8864405 9207624 9226436 9325852 9333954 9281897 9345103	M1 M1 M6 M6 M6 M30A1 M31A1E1	5.0 13.5 20.5 20.5 20.9 26.0 28.0	8864406 71-9-180 71-9-269 71-9-269 71-9-269	M82	9330 m 14320 m 17740 m 17740 m .2500 m	358.3	7548187 9234357 9293303 9234357 9234357	8837839
Steel	HF-1	9326055	M557 M739 M564 M732	PD PD MTSQ PROX	8863535 9258602 10534285 11716451	M3A1 M4A2 M119 M119A1 M119A2 M203 M203A1	8882277 9207624 9226436 9325852 9333954 9281897 9345103	M1 M1 M6 M6 M6 M31A1E1 M31A1E1	5.5 13.5 20.5 20.5 20.9 26.0 28.0	–	9/ 15/	–	–	–	9329574

13/ Fired from howitzer.
14/ Base charge 1 plus increments 2, 3, 4 & 5: Max Range 10820 yards; Muzzle Velocity 1230 FPS.
15/ Primer, Percussion, M82 Dwg 8861197, is used with ammunition when fired from Howitzer, SP, M109, M109A1, M109A2, M109A3 and M198.
16/ Projectile, 155MM: HE, M107 B2 w/o Fuze for How M1, M1A1, M46. Obsolete for U.S. Army use. Std A for U.S. Marine Corps use. AMCTC 6558.
17/ Fuze, Inert, M1907 obsolete AMCTC 6558.
18/ M549, M549A1 projectile not to be fired below charge 7 and only M549A1 can use M203 charge in M199 cannon.
Max Range 17,740 (MTRS)
MV 650 (M/S)
19/ M823 Projectile is the training round for the M712 copperhead projectile only.
20/ Propelling Charge M19 Obsolete MSR 11756003
21/ Propelling Charge M119 Series cannot be used with M109A1 Howitzer when using the M712 projectile.
22/ Projectile M804 cannot be fired above charge 5 and at charge 1.
23/ Propelling Charge M203/M203A1 fired from M199 cannon only.

CHART 14. 165-MILLIMETER AMMUNITION

LINE NO.	CARTRIDGE								PROJECTILE							
	TYPE-CLASSI-FICA-TION	MSR, AMCTCM OR OTCM NO	MODEL DESIG-NATION	TYPE	NOMINAL WT (LB)	ASSEMBLY DWG NO.	SPEC NO.	MODEL OF CANNON	PROJEC-TILE ASSEMBLY DWG NO.	FILLER			COMPONENTS			METAL PARTS ASSEMBLY DWG NO.
										COM-POSI-TION	WT (LB)	DWG NO.	KIND	WT (LB)	DWG NO.	
1	STD STD	4266	M123A1 M123	HEP	65.00	8845042	MIL-C-45467	Gun M135	8845043	Comp A-3 Comp A-6	16 20	8845043	—	—	—	8845046
2	STD	8415	M623	TP	65.00	9219045	MIL-C-50413	Gun M135	9219046	Inert	36	9219046	—	—	—	10551955 10543024

1/ Handle Assembly, Dwg 8845053, to Cartridge Case.
2/ Also Charge, Ignition Supplementary, Black Powder 220 grains, Dwg 8845064.
3/ Information classified.

CHART 14. 165-MILLIMETER AMMUNITION

			FUZE			PROPELLING ASSEMBLAGE									PERFORMANCE		PACKING	
BODY						CARTRIDGE CASE		PROPELLANT			PRIMER							
MATERIAL	MATERIAL FORM	DWG NO.	DESIGNATION	TYPE	DWG NO.	DESIGNATION	DWG NO.	COMPOSITION	NOM WT (LB)	DWG NO.	DESIGNATION	TYPE	DWG NO.	MAX RANGE (YD/M)	MV (fps/mps)	INNER PACK DWG NO.	OUTER PACK DWG NO.
Steel	Plate	8845046	M62A2	BD	8886414	M104 1/	8845066	M2 2/	2.12	8845054	M73	Elec	8840278	3/	3/	8796483	8796482
Steel	Plate	10551955	Base Plug	—	—	M104	8895066	M2	2.12	8845054	M73	Elec	8840278	—	—	8796483	8796482

CHART 15. 175-MILLIMETER AMMUNITION

PROJECTILE																
										FILLER			COMPONENTS			
LINE NO.	TYPE CLASSI-FICA-TION	MSR, AMCTCM OR OTCM NO.	MODEL DESIG-NATION	TYPE	NOMINAL WT (LB)	ASSEMBLY DWG NO.	SPEC NO.	MODEL OF CANNON	LOADING ASSEMBLY DWG NO.	COM-POSI-TION	WT (LB)	DWG NO.	KIND	WT (LB)	DWG NO.	METAL PARTS ASSEMBLY DWG NO.
1	STD	2819	M458	Dummy	148.7	XP115656	PA-PD-2526	Gun M113 M113A1	--	--	--	---	Suppl Chg	--	XP107246	XP115656
2	STD STD	3089	M437A2 M437A1	HE	147.0	8837902	MIL-P-45455	Gun M113 M113A1	--	Comp B TNT	31 30	8837902	1/ Suppl Chg	0.365	8797090	10520193

1/ For M437A2 and M437A1
2/ A fired service primer is used.
3/ 36740
4/ w/suppl chg removed.

CHART 15. 175-MILLIMETER AMMUNITION

BODY			FUZE			PROPELLING ASSEMBLAGE						PERFORMANCE		PACKING	
						PROPELLING CHARGE ASSEMBLY		PROPELLANT		PRIMER					
MATERIAL	MATERIAL FORM	DWG NO.	DESIGNATION	TYPE	DWG NO.	DESIGNATION	DWG NO.	DESIGNATION	NOM WT (LB)	DESIGNATION AND TYPE	DWG NO.	MAX RANGE yd (m)	MV fps (mps)	INNER PACK DWG NO.	OUTER PACK DWG NO.
Steel	--	XP115658	M73	Dummy	8796863	M98	9205873	--	55	2/ M82	--	--	--	--	8857344
Steel	Forg	10520195	M739 M572 or M582 M728 4/ M732	PD PD MTSQ PROX PROX	9258602 8880696 9236700 11718406 11716451	M86 M86A1 & M86A2 Series M124	8837905 9223106	M6 M6	55 57 16.75	M82	8861197	3/	3000	--	8857344

1464/1710

CHART 16. 8-INCH AMMUNITION

PROJECTILE																
										FILLER			COMPONENTS			
LINE NO.	TYPE-CLASSI-FICA-TION	MSR, AMCTCM OR OTCM NO	MODEL DESIG-NATION	TYPE	NOMINAL WT (LB)	ASSEMBLY DWG NO.	SPEC NO.	MODEL OF CANNON	LOADING ASSEMBLY DWG NO	COM-POSI-TION	WT (LB)	DWG NO.	KIND	WT (LB)	DWG NO.	METAL PARTS ASSEMBLY DWG NO
1	STD	37838	M426	Agent	197	8860620-1	MIL-P-46678	How M2 M2A1 M47 M2A2 M201A1	8860620-1	GB Non Pers	14.5	8860619	10/	7.0	8860628	10522517
2	STD	37838	M426	Agent	197	8860620-2	MIL-P-46678	How M2 M2A1 M47 M2A2	8860620-2	VX Pers	14.5	8860622	10/	7.0	8860628	10522517
3	OBS	09806004	M14	Dummy	200	72-1-82	--	M201 Series How M2 M2A1 M2A2 M47 M201	--	--	--	--	--	--	--	72-1-82
	STD	09806005	M845	Dummy	200	9340711	ANSI-Y14.5 1973		9333956	--	--	9341606	--	--	--	9335660
4	OBS	37119	MK1A1	Dummy	188.6	--	--	M201 Series How M2 M2A1 M47 M2A2	--	--	--	--	--	--	--	72-1-29
5	OBS	36569	M103	HE	241.07	--		Gun M1	75-14-258	TNT	20.9	75-14-258	Booster M21A4		8798183	75-4-87
6	STD	36841	M106	HE	201	--	MIL-P-46258	How M2 M2A1 M47 M2A2 M201 M201A1	9207909	TNT	36.3	9207909	Suppl Chg	0.365	8797090	10534909
7	STD	2873	M404	HE	200	8875941	MIL-P-50257	How M2 M2A2 M47 M2A1 M201 M201A1	8875941	A5	4.9	MIL-E-14970	104 M43A1 Gren	52.1	8875900	8875940
8	STD	12806008	M509A1	HE	206.5	9210140	--	M201 M201A1	9210140	A5	12.07	MIL-E-14970	180 M42 Gren	82.8	9215340	10551896
9	STD	01796002	M650	HE-RA	200	9287994	MIL-P-63142	How M2A2 M201 M201A1	9287993	TNT	26.0	9288022 9288021	Booster Comp A-5 Booster Aux Comp A-5	2.0 oz 0.7 oz	9288023 9287977	9287954

1/ Zones 1 through 5, Green Bag
2/ Zones 5 through 7, White Bag
3/ M188 Charge Zone 8
4/ M188A1 Charge Zone 8 and 9

5/ Primer, Percussion, MK2A4, Dwg 8840362, for How M2, M2A1
6/ Primer, Percussion - Electric, MK15 Mod 1, Dwg. 74-8-5, and Primer, Electric, MK34 Mod 0, Dwg 439166, for How M47, M55, and Primer, Percussion - Electric, MK15 Mods 2 and 3, for How M2A2
7/ Supplementary Charge Removed

8/ Primer, Percussion, M82, Dwg 8861 (and M201A1)

9/ FPS, Reduced Charge $\frac{M9}{2100}$ $\frac{M10}{2600}$
FPS, Normal Charge 2600 2850

8/ Primer, Percussion, M82, Dwg 8861197, for M47, M2A2 and M201 (and M201A1)

9/ FPS, Reduced Charge $\frac{M9}{2100}$ $\frac{M10}{2600}$
FPS, Normal Charge 2600 2850

10/ Burster, Projectile, M83, Comp B-4
11/ Inert Material
12/ M2 Series M47 Cannon

CHART 16. 8-INCH AMMUNITION

BODY			FUZE			PROPELLING ASSEMBLAGE								PERFORMANCE		PACKING
						PROPELLING CHARGE ASSEMBLY		PROPELLANT			PRIMER					
MATERIAL	MATERIAL FORM	DWG NO.	DESIGNATION	TYPE	DWG NO.	DESIGNATION	DWG NO.	DESIGNATION	NOM WT (LB)	DWG NO.	DESIGNATION	TYPE	DWG NO.	MAX RANGE (yd/m)	MV fps/mps	DWG NO.
Steel	Forg	1052216	M739 M557 M728 7/ M732	PD PD VT PROX	9258602 8863535 11718400 11716451	1/M1 2/M2	8860491 8861374	M1 M1	13.30 28.30	8860491 8861374	5/ 6/ 8/	5/ 6/ 8/	5/ 6/	16008 (14407m) 12/	11/1380 421 mps 1950 (595 mps) 12/	7548346
Steel	Forg	10522518	M739 M557 M728 7/ M732	PD PD VT PROX	9258602 8863535 11718400 11716451	1/M1 2/M2	8860491 8861374	M1 M1	13.30 28.30	8860491 8861374	5/ 6/ 8/	5/ 8/	5/ 6/	16008 (14407m) 12/	1950 (595 mps) 12/	7548346
Steel Steel	Cast Cast	72-1-83 9336660	-- M51A5	-- Inert	-- --	M4 M4	8863354 8863354	11/ 11/	28.75 28.75	8863383 8863383	Fired Primer Only Fired Primer Only	-- --	-- --	-- --	-- --	76-3-9
Steel	Cast	72-1-29	--	--	--	M4	8863354	11/	28.75	8863383	Fired Primer Only	--	--	--	--	76-3-9
Steel	Forg	75-4-87	M557	PD	8863535	M13 M10 M9	71-9-227 71-9-213 71-9-209	M6 Smk- less	90.00 92.00 75.00	71-9-227 71-9-213 71-9-209	MK2A4	Perc	8840362	--	9/	76-2-79
Steel	Forg	10534910	M76 M739 M557 M728 7/ M732 M564 M572	-- PD PD PD VT PROX MTSQ PD	73-2-214 9258602 8863535 11718400 11716451 10534285 8880696	1/M1 2/M2 3/M188 4/M188A1	8860491 8861374 9277173 11829092	M1 M1 M30A2 M31A1	13.30 28.30 41.00 49.00	8860491 8861374 MIL-P- 48181C 11829092	5/ 6/ 8/	5/ 6/ 8/	5/ 6/ 8/	16008 (14407m) 12/	1950 (595 mps) 12/	7548346
Steel	Forg	8875940	M565 (Mod) M577 M548	MT MTSQ MTSQ	10522991 9236500 10520638	1/M1 2/M2	8860491 8861374	 M1 M1	13.30 28.30	8860491 8861374	5/ 6/ 8/	5/ 6/ 8/	5/ 6/ 8/	18368 (16531m) 12/	1950 (595 mps) 12/	7548346
Steel Alum.	Forg	10551897	M577	MTSQ	9236500	1/M1 1/M2 3/M188 4/M188A1	8860491 8861374	M1	13.30 28.30	8860491 8861374	8 6/	8/ 6/	8/ 6/	16,000	594.4	9229038
Steel	Alloy HF-1	9287993 9287943 9287954	M557 M572 M739	PD PD PD	8863535 8880696 9258602	M1 M2 3/M188 4/M188A1	8860491 8861374 9277173 11829092	M1 M1 M30A2 M31A1	13.30 28.30 41.00 49.00	8860491 8861374 MIL-P- 48181C 11829092	8/	Perc	8861197	--	--	9280132

CHART 17. AMMUNITION FOR SUBCALIBER WEAPONS
(Guns and Howitzers)

CARTRIDGE							PROJECTILE							FUZE		
							LOADING				METAL PARTS	BODY				
LINE NO.	TYPE-CLASSI-FICA-TION	MSR, AMCTCM OR OTCM NO.	CALIBER	MODEL DESIG-NATION	TYPE	NOMINAL WT (LB)	ASSEMBLY DWG NO.	ASSEMBLY DWG NO.	FILLER COMPO-SITION	WT (LB)	ASSEMBLY DWG NO.	MATE-RIAL	MATE-RIAL FORM	DESIG-NATION	TYPE	DWG NO.
1	OBS	11816011	37MM	M63 MOD1	TP	2.01	8831141	8831142	BP	0.084	8597556	Steel	Bar or Forg	M58	BD Prac-tice	8831146
2	OBS	11816011	37MM	M492	TP	--	--	--	--	--	--	--	--	--	--	--
3	STD	37119	37MM	M63	TP	--	--	--	--	--	--	--	--	--	--	--
4	STD	36841	--	--	--	--	--	--	--	--	--	--	--	--	--	--
5	STD	36841	--	--	--	--	--	--	--	--	--	--	--	--	--	--
6	STD	37198	--	--	--	--	--	--	--	--	--	--	--	--	--	--
7	STD	36841	--	--	--	--	--	--	--	--	--	--	--	--	--	--

CHART 17. AMMUNITION FOR SUBCALIBER WEAPONS (Guns and Howitzers)

PROPELLING ASSEMBLAGE							PERFORMANCE		PACKING		WEAPON			
CARTRIDGE CASE		PROPELLANT		PRIMER							SUBCALIBER ASSEMBLAGE			
DESIGNATION	DWG NO.	DESIGNATION	NOM WT (LB)	DESIGNATION	TYPE	DWG NO.	MAX. RANGE (YD) yd (m)	MV (FPS) fps (mps)	INNER PACK DWG NO.	OUTER PACK DWG NO.	GUN CAL & TYPE DESIGN	GUN MOUNT	MOUNT DESIG	PARENT GUN CAL & TYPE DESIGNATION
MK1A2 MK1A2B1	8596159	M2	0.56	M23A2	Perc	8831161	4980	1100	8833505	76-1-1263	37MM Gun M12	Ext	--	75MM How M1A1, M2 LVT (A) 4 & LVT (A) 5
--	--	--	--	--	--	--	--	--	--	--	37MM Gun M13	Int	--	105MM How M2A1, M2 Ser, M4 Ser
--	--	--	--	--	--	--	--	--	--	--	37MM Gun M14	Int	--	90MM Gun M1, M1A1, M3
--	--	--	--	--	--	--	--	--	--	--	37MM Gun M15	Int	--	76MM Gun M1A2, M1A1C, M4 on 76MM SP
--	--	--	--	--	--	--	--	--	--	--	37MM Gun M1916	Ext	M5	75MM Pack How M1 LVT (A) 4 & LVT (A) 5
--	--	--	--	--	--	--	--	--	--	--	37MM Gun M1916	Ext	M10	155MM Gun M2 & 8-Inch How M1
--	--	--	--	--	--	--	--	--	--	--	37MM Gun M1916	Ext	M13A1	155MM Gun M2 & 155MM How M1, M1A1, M1A2

CHART 18. AMMUNITION FOR 60MM AND 81MM MORTAR TRAINING DEVICE
(SABOT WITH 22-MM SUBCALIBER CARTRIDGES)

CARTRIDGE								PROJECTILE	
								LOADING	BODY
LINE NO.	TYPE-CLASSI-FICA-TION	MSR, AMCTCM OR OTCM NO.	CALIBER	MODEL DESIG-NATION	TYPE	NOMINAL WT (LB)	ASSEMBLY DWG NO.	FILLER COMPO-SITION	MATE-RIAL
1	STD	06806010	60MM Sabot	M3	Tng	6.25	9328601	N/A	Alum
2	STD	05756032	81MM Sabot	M1	Tng	8.5	9287906	N/A	Alum
3	STD	05756032	22MM	M744	Practice	1.097	9287907	BP .03	Steel
4	STD	05756032	22MM	M745	Practice	1.097	9287908	BP .04	Steel
5	STD	05756032	22MM	M746	Practice	1.097	9287909	BP .06	Steel
6	STD	05756032	22MM	M747	Practice	1.097	9287910	BP .08	Steel

CHART 18. AMMUNITION FOR 60MM AND 81MM MORTAR TRAINING DEVICE
(SABOT WITH 22-MM SUBCALIBER CARTRIDGES)

PERFORMANCE		PROPELLING ASSEMBLAGE		PACKING		
MAXIMUM RANGE	MUZZLE VELOCITY	CARTRIDGE CASE	PROPELLANT	INNER PACK DWG NO.	OUTER PACK DWG NO.	WEAPON
3 to 51 ft 1 to 15 mtrs	--	--	--	--	9329480	60MM M19, M224, M2
3 to 51 ft 1 to 15 mtrs	--	--	--	--	9329480	81MM M1, M29A1,M29
639 ft 195 mtrs	148 fps 45 mps	9299079	CHARGE 1 .03 oz	9322198	9322201	60MM 81MM M19 M1 M224 M29A1 M2 M29
770 ft 235 mtrs	164 fps 50 mps	9299079	CHARGE 2 .04 oz	9322198	9322201	60MM 81MM M19 M1 M224 M29A1 M2 M29
1082 ft 330 mtrs	197 fps 60 mps	9299079	CHARGE 3 .06 oz	9322198	9322201	60MM 81MM M19 M1 M224 M29A1 M2 M29
1427 ft 435 mtrs	230 fps 70 mps	9299079	CHARGE 4 .08 oz	9322198	9322201	60MM 81MM M19 M1 M224 M29A1 M2 M29

CHART 19. AMMUNITION FOR SUBCALIBER 4.2-INCH MORTAR WEAPONS

	CARTRIDGE						PROJECTILE							FUZE		
							LOADING				METAL PARTS	BODY				
LINE NO.	TYPE CLASSI-FICA-TION	MSR, AMCTCM OR OTCM NO.	CALIBER	MODEL DESIG-NATION	TYPE	NOMINAL WT (LB)	ASSEMBLY DWG NO.	ASSEMBLY DWG NO.	FILLER COMPO-SITION	WT (LB)	ASSEMBLY DWG NO.	MATE-RIAL	MATE-RIAL FORM	DESIG-NATION	TYPE	DWG NO.
1	STD	37119	60MM	M49A2	HE	3.07	75-1-82	75-14-257	Flake TNT	0.34	75-2-288	Steel	Forg	M52A1 2/ M525	PD	73-1-161 8800197
2	OBS	37344	60MM	M50A2	TP	3.09	75-1-83	75-14-238	1/	0.29	75-2-288	Steel	Forg	M52A1 2/ M525	PD	73-1-161
3	STD	37119	60MM	M69	Tng.	4.43	9222944	--	--	--	9222944	Iron	Cast	--	--	--

	CARTRIDGE							PROJECTILE	
								LOADING	BODY
LINE NO.	TYPE CLASSI-FICA-TION	MSR NUMBER	CALIBER	MODEL DESIG-NATION	TYPE	NOMINAL WT (LBS)	ASSEMBLY DWG NO.	FILLER COMPO-SITION	MATE-RIAL
1	STD	11846006	4.2 In. Sabot	M4	Training	21.4	9357759	N/A	Alum.
2	STD	11846006	22MM	M890	Practice	.97	9357760	Yellow Smk Chg 6 grams	Steel
3	STD	11846006	22MM	M891	Practice	.97	9357761	Yellow Smk Chg 6 grams	Steel
4	STD	11846006	22MM	M892	Practice	.97	9357762	Yellow Smk Chg 6 grams	Steel
5	STD	11846006	22MM	M893	Practice	.97	9357763	Yellow Smk Chg 6 grams	Steel
6	STD	11846006	22MM	M894	Practice	.97	9357764	Yellow Smk Chg 6 grams	Steel
7	STD	11846006	22MM	M895	Practice	.97	9357765	Yellow Smk Chg 6 grams	Steel
8	STD	11846006	22MM	M896	Practice	.97	9357766	Yellow Smk Chg 6 grams	Steel
9	STD	11846006	22MM	M897	Practice	.97	9357767	Yellow Smk Chg 6 grams	Steel

1/ Inert Cast Filler C.
2/ Fuze, PD, M52 Series Obsolete AMC TC 6558

CHART 19. AMMUNITION FOR SUBCALIBER 4.2-INCH MORTAR WEAPONS

PROPELLING ASSEMBLAGE							PERFORMANCE		PACKING		WEAPON			
CARTRIDGE CASE		PROPELLANT		PRIMER							SUBCALIBER ASSEMBLAGE			
DESIGNATION	DWG NO.	DESIGNATION	NOM WT (LB)	DESIGNATION	TYPE	DWG NO.	MAX. RANGE (YD) yd (m)	MV (FPS) fps (mps)	INNER PACK DWG NO.	OUTER PACK DWG NO.	GUN CAL. & TYPE DESIGN	GUN MOUNT	MOUNT DESIG	PARENT GUN CAL & TYPE DESIGNATION
--	--	M3A1	0.021	M32	Perc	8880637	1978 603 m	Chg 4 518 168 mps	7549170	8796472	60MM Mort M31	Int	—	4.2-inch Mort M30
--	--	M2	0.021	M32	Perc	8880637	1978 603 m	Chg 4 518 168 mps	7549170	8796472	--	--	--	
--	--	--	--	--	--	--	235 72 m	152.5 38.5 mps	--	791562	--	--	--	

PERFORMANCE		PROPELLING ASSEMBLAGE		PACKING		WEAPON
MAXIMUM RANGE	MUZZLE VELOCITY	CARTRIDGE CASE	PROPELLANT	INNER PACK DWG. NO.	OUTER PACK DWG. NO.	MODEL NO.
5 meters	—	N/A	N/A	N/A	16A6.5 German	M30
196 meters 214 yards	44 mps 144 fps	—	Ejec Chg 1 4 grams Prop Chg (BP) .5 grams	N/A	107.11 German	M30
235 meters 256 yards	48 mps 157 fps	—	Ejec Chg 2 4 grams Prop Chg (BP)	N/A	107.11 German	M30
275 meters 301 yards	52 mps 171 fps	—	Ejec Chg 3 4 grams Prop Chg (BP)	N/A	107.11 German	M30
319 meters 349 yards	56 mps 184 fps	—	Ejec Chg 4 4 grams Prop Chg (BP)	N/A	107.11 German	M30
365 meters 399 yards	60 mps 197 fps	—	Ejec Chg 5 4 grams Prop Chg (BP)	N/A	107.11 German	M30
416 meters 455 yards	64 mps 210 fps	—	Ejec Chg 6 4 grams Prop Chg (BP)	N/A	107.11 German	M30
470 meters 514 yards	68 mps 233 fps	—	Ejec Chg 7 4 grams Prop Chg (BP)	N/A	107.11 German	M30
528 meters 577 yards	72 mps 236 fps	—	Ejec Chg 8 4 grams Prop Chg (BP)	N/A	107.11 German	M30

CHART 20. BLANK AMMUNITION

CARTRIDGE										
									CARTRIDGE CASE	
	TYPE-CLASSI-FICA-TION	MSR, AMCTCM OR OTCM NO.	CALIBER	DESIG-NATION	NOMINAL WT (LB)	ASSEMBLY DWG NO.	SPEC NO.	MODEL OF CANNON	DESIG-NATION	DWG NO.
1	STD	4371	75MM	M337A2	3.25	7549273	MIL-C-45459	Gun - M3, M5 How - M1A1, M1A1C	M9A1 M9A1E 1	8861524 10521899
2	OBS	36841	75MM		3.07	75-1-67	MIL-A-20337	Gun - M3 How - M1A1, M1A1C	M9A1	8861524
3	OBS	36841	75MM		2.68	75-1-107	MIL-A-20337	Gun - M3 How - M1A1, M1A1C	M9A1	8861524
4	OBS	11756003	76MM	M351	4.0	7549272	MIL-A-20337	How - M1A1, M1A1C	M29	71-2-133
5	OBS	11756003	76MM	M355A2	4.33	7549267	MIL-A-20337	Gun - M32, M48	M10B1 (Steel) M10 (Brass)	7548121 71-2-196
6	OBS	11756003	90MM	M394	8.23	7549210	MIL-C-45490	Gun - M36, M41, M54	M27 M27B1	8857214
7	STD	38091	105MM	M395	6.24	7549251	MIL-C-46229	How - M2A1, M2A2 M49, M103, M137	M15 M15B1	8845003

CHART 20. BLANK AMMUNITION

COMPONENT PARTS								PACKING	
CHARGE		PRIMER				CLOSING CUP			
COMPOSITION	WT (LB)	TYPE LOADING	DESIG-NATION	TYPE	DWG NO.	MATERIAL	DWG NO.	INNER PACK DWG NO.	OUTER PACK DWG NO.
Blk. Pwd. Pot. Nit.	1.00	Loose	M1B1A2	Perc	8839474 8839453	Plastic	7549272	7549269	7549268
Blk. Pwd. Sod. Nit.	0.87	Double Pellet	M1B1A2 M1A2	Perc	8839474 8839453	Paper-board	7549253	7549269	7549150
Blk. Pwd. Sod. Nit.	0.43	Single Pellet	M1B1A2 M1A2	Perc	8839474 8839453	Paper-board	7549253	7549269	7549268
Blk. Pwd. Sod. Nit.	0.42	Loose	M1B1A2	Perc	8839474	Paper-board	7549253	7549269	76-1-528
Blk. Pwd.	1.25	Bag	M70	Perc	8838131	Paper-board	7549266	7548523	7548524
Blk. Pwd. Pot. Nit.	1.75	Loose	M1A2	Perc	8839453 8839474	Plastic	7549212	7549250	7549249
Blk. Pwd.	1.7	Loose	M1A2 M1B1A2	Perc	8839453 8839474	Plastic	7549253	7549255	7549255

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The thesis that air operations at night are evolving as doctrinal employment of air power for counterinsurgency is founded basically on the history of night air operations in Vietnam during the period 1962 through 1964. It became evident in 1962 that the developing pattern of conflict in Vietnam was a repetition of the insurgency/counterinsurgency experiences of other countries in previous times. Without regard to other factors, it was apparent that, militarily, history was repeating itself in Southeast Asia. Insurgent activity was largely night oriented, and the counterinsurgent was ill-prepared to conduct effective ground or air operations against the illusive night-fighting guerrilla. During 1963, night air operations developed rapidly and the tools, tactics, and techniques which were to bring significant results during 1964 were developed. A statistical analysis of the air operations during 1964 illustrates beyond doubt that the employment of air power at night was evolving as a normal, and in fact desirable utilization of this combat capability. The use of air power at night is evolving and will continue to evolve as doctrine for unconventional warfare.

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AN EVOLVING DOCTRINE FOR COUNTERINSURGENCY (U)

An abstract for a thesis presented to the Faculty of
the U. S. Army Command and General Staff College in
partial fulfillment of the requirements of the
degree

MASTER OF MILITARY ART AND SCIENCE

by

DAVID M. MURANE, Major, USAF

Fort Leavenworth, Kansas
1965

U. S. ARMY COMMAND AND GENERAL STAFF COLLEGE

Name of Candidate David M. Murane, Major, USAF

Title of Thesis NIGHT AIR OPERATIONS IN VIETNAM; AN EVOLVING DOCTRINE FOR COUNTERINSURGENCY (U)

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The opinions and conclusions expressed herein are those of the individual student author and do not necessarily represent the views of either the United States Army Command and General Staff College or any other governmental agency. (References to this study should include the foregoing statement.)

ABSTRACT

The thesis that air operations at night are evolving as doctrinal employment of air power for counterinsurgency is founded basically on the history of night air operations in Vietnam during the period 1962 through 1964.

It became evident early in 1962 that the developing pattern of conflict in Vietnam was a repetition of the insurgency/counterinsurgency experiences of other countries in previous times. Without regard to other factors, it was apparent that, militarily, history was repeating itself in Southeast Asia. Insurgent activity was largely night oriented, and the counterinsurgent was ill-prepared to conduct effective ground or air operations against the illusive night-fighting guerrilla.

Although the insurgent commonly exploits night for his terrorist activities, he does this not by choice but of necessity. An examination of basic factors and problems inherent in night military operations reveals the significant disadvantages which face both the insurgent and the counterinsurgent. The simple inability to see in the dark and the resultant effect of complicating movement and control, increasing susceptibility to injury and fatigue, and prolonging the time which it takes to perform a military maneuver--these are the problems faced by the military man at night, regardless of his mission and irrespective of the environment in which he fights. Night is no less an enemy to soldiers on the ground than it is to airmen in the sky.

Night, however, if examined as a potential ally, offers an environment which, when properly exploited, can be of tremendous value to both

the insurgent and the counterinsurgent.

In Vietnam, this exploitation was practiced from the beginning by the Viet Cong with ever increasing success. The Factors of cover, concealment, secrecy, and surprise were utilized with devastating effectiveness by the Viet Cong in their mission of expanding communism into the Republic of South Vietnam.

In response to the increasing enemy threat during the hours of darkness, the South Vietnamese and their American advisors began in mid-1962 to develop a capability to neutralize and eventually defeat the insurgents by shifting emphasis to counterinsurgent operations at night, both on the ground and in the air.

From an inauspicious beginning in which the primary weapon and deterrent was the flareship, night air and ground operations expanded to include flareship-fighter strike teams and specially trained small unit ground forces meeting the Viet Cong in the environment which they (the Viet Cong) had chosen to exploit.

During 1963, night air operations developed rapidly and the tools, tactics, and techniques which were to bring significant results in 1964 were developed. A statistical analysis of the air operations during 1964 illustrates beyond doubt that the employment of air power at night was evolving as a normal and, in fact, desirable utilization of this potent combat capability.

The trends point unmistakably to a full realization of the part which airborne weapons and personnel can play in counterinsurgency when employed at night.

During this same period, many tests and experiments were conducted in Vietnam to improve our night air capability, and tactics, techniques, and equipment used in other counterinsurgency wars were examined, to be

used or discarded as dictated by the peculiarities of the Vietnamese battlefield.

The value of using the night as a means to reduce the vulnerability of aircraft to an increasing Viet Cong antiaircraft capability was recognized and more and more ground and air operations were conducted in the newly emerging friendly environment of darkness.

The evolution of night air operations in Vietnam occurred with relative celerity as both Army and Air Force men became aware of the potential advantages inherent in employing aircraft in support of offensive as well as defensive operations on the ground. An indication of this awareness has been manifested in increasing emphasis on the part of all the services on the use of air power at night.

In Counterinsurgency warfare in the future, lessons learned in Vietnam, if remembered and if exploited, will serve as a doctrinal basis for immediate employment of night air operations as one of the most important and most lucrative methods of defeating insurgent forces.

The use of air power at night is evolving and will continue to evolve as doctrine for unconventional warfare with the objective and ultimate result of providing a credible deterrent to communist insurgency. This deterrent is based on the capability to conduct effective military operations 'round the clock, utilizing balanced air and ground forces to defeat insurgency anywhere in the world.

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[signature], Research and Thesis Monitor

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INTRODUCTION

Uncounted words have been spoken and recorded, written and published by uncounted experts and pseudo-experts on the subject of Vietnam. The country, the climate, the people, the politics, the implications and complications, solutions and salvations--these and many others have been topics for lengthy discussion and debate. It was therefore, with some reluctance, that the author approached an admittedly arduous task which would add to this already ponderous collection of biased and unbiased opinion, fact, fiction, and fantasy. The reluctance was also due to anticipated, and since confirmed, difficulty in extracting one part of the problem in Vietnam from the general enigma. And in Vietnam, interrelation of specific problems in particularly characteristic of the whole conundrum. It is almost impossible to discuss a Vietnamese military problem without reference to the political structure which fosters that problem. It is equally difficult to discuss night air operations without considerable attention to both ground and air operations in general, and again, the relationship of ground and air operations to the overall military and paramilitary effort. However, as is often the case, motivation to examine in detail, and perhaps solve a part of a heretofore insolvable riddle transcends reluctance. In this instance a personal experience provided additional incentive.

To set the stage for this thesis and to establish the author's claim to "expert" status, we return to February 1962. It was during

this month that ten hastily trained air operations officers arrived in South Vietnam to take over, on a permanent party basis, operations of the newly organized Tactical Air Control System (TACS). Duty for the next twelve months was in Pleiku, a small town located in the Central Highlands, 210 miles northeast of Saigon. Headquarters for the Army of Viet Nam (ARVN) II Corps, it was also headquarters for one of the three Air Support Operations Centers (ASOC), which, with the Joint Operations Center (JOC) at Saigon and associated radar stations, made up the TACS in Vietnam. As a Close Air Support Duty Officer (CASDO) in Second ASOC, the author was an advisor to the Viet Nam Air Force (VNAF) officers assigned there on all matters pertaining to employment of available VNAF/USAF air effort.

The ensuing year was, for the most part, a study in frustration. Not enough airplanes, not enough pilots, not enough anything. We were able to accomplish what we did during that austere period (and in retrospect it seems precious little), only by dogged determination and unlimited patience. It was in this environment that the thesis motivating personal experience occurred.

From the beginning of the tour in Vietnam, the most frustrating experiences were associated with Viet Cong (VC) attacks on villages, hamlets, and outposts during the hours of darkness. In the majority of cases, word of an attack was not received until the next day, and in some instances, several days had passed before a report filtered up through the ponderous civil/military chain of command. A great amount of time, effort, and resources was expended by MAAG, Special Forces, the United States Overseas Mission (USOM) personnel in attempts to provide these isolated spots of humanity with a means to call for help when the inevitable attack came. As these efforts began to bear fruit

and the "fire alarm" system expanded, it became painfully evident that an alarm system in itself was of little value if the "fire horse" balked in the barn. At that time (the summer months of 1962), ARVN troops were reluctant to venture forth at night on a rescue mission, and due to lack of training the VNAF capability to perform night air operations was very limited. U. S. Air Force night air capability was also restricted due, primarily, to lack of aircraft. Recognizing this defensive weakness, U. S. advisors had been applying pressure to ARVN and VNAF commanders in an attempt to provide some sort of night "fire fighting" force. Specific actions taken by the ARVN in this respect are not known but it is significant to note that as of the end of 1964, Military Assistance Command, Vietnam (MACV) weekly Military Reports (MILREPS) still contain repeated instances of ARVN reinforcements waiting until dawn to go to the aid of an outpost or village which had undergone a night attack. The VNAF was also slow in responding to the need. Early in the summer of 1962, the 1st Air Commando Squadron (USAF), at Bien Hoa Airfield, had developed a capability to drop parachute flares from SC-47 aircraft. They were subsequently put on ground alert by the JOC. Their mission was to support beleagured outposts with flare illumination. The VNAF followed suit during August with C-47 flareships on alert at Tan Son Nhut Airfield in Saigon. There had been several instances during June and July when flareships alone had caused the Viet Cong to break off an attack, and both VNAF and USAF commanders were anxious to exploit this new capability. This was more of a "fire-fly" force than a "fire-fight" force, however, it was, at least at that time, proving to be effective. At about the same time (the first week in September), the 22d Division (ARVN), at Kontum (40 kilometers north of Pleiku), reported that reliable intelligence sources

were predicting a large scale attack on ARVN military installations in the Kontum area. On the basis of these reports, II Corps requested, through the ASOC, that a flare aircraft be placed on ground alert at Pleiku Airfield. There was a great deal of haggling on the unpredictable and unreliable TROPOSCATER telephone between VNAF officers at II ASOC and VNAF officers at the JOC before the request for flareship was approved (Pleiku was considered hardship duty by the Vietnamese, as is any place outside of Saigon). However, late the next day, a VNAF C-47 manned by a Vietnamese pilot and an American co-pilot arrived at Pleiku with a load of parachute flares and the people necessary to throw them out the door. The American co-pilot reported to the ASOC where he was briefed on local flying conditions and possible targets which they might be called upon to illuminate. the VNAF pilot disappeared after landing and couldn't be located (he may be lost to this day). A new runway had only recently been completed at Pleiku, and the runway lighting system was not operational due to electrical power problems. However, the chief of the MAAG Airbase Advisory Team (ABAT) had secured sufficient battery powered portable lights to assure a safe night take-off and landing. Secure in the knowledge that Kontum was certainly in good hands tonight, everyone slept a little easier. It, therefore, was only mildly annoying to be awakened at midnight by a call from the Corps Tactical Operations Center (CTOC) duty officer advising us that a village was under attack and that our help was needed. The C-47 co-pilot was awakened, and together we went to the ASOC. The ASOC Director (an unforgettable VNAF Captain) met us at the door with the words, "Will you please call Bien Hoa and ask them to send a flareship?" The ensuing repartee, if not under such tragic circumstances, would certainly have qualified as high humor.

It was finally resolved that the VNAF C-47 pilot, who could not be found, was not qualified to fly at night anyway, and the portable runway lights were not considered adequate by the VNAF ASOC Director. The American co-pilot offered to perform the mission without the VNAF pilot, but the ASOC Director would not permit him to fly the VNAF C-47. When it became obvious that our local flareship illumination capability had been only "eyewash," we did, in fact, call Bien Hoa, and one hour and forty-five minutes later a USAF SC-47 dropped its first flare over the village of Plei Mrong. During that one hour and forty-five minutes wait, over ninety people lost their lives. The Special Forces Team which normally occupied the village had gone on night patrol with the bulk of the self defense force, and the VC, in typical fashion, had attacked the defenseless force that remained.

In retrospect, it is not possible to emphatically conclude that a more rapid response by a flareship alone would have made a difference in the eventual outcome; but at that stage in the war, probability is great that it would have.

We have cited only one instance. One which was particularly stark however, in its impact. There were others, less vivid individually, but together forming a memory of futility and lack of preparedness to fight the battle at night, whether on the ground or in the air. An enemy that moves at night and fights at night must be counter-moved and counter-fought at night. This realization has been all too slow in coming, and to this day is not receiving the emphasis which it must have if we are to retain some hope of defeating communist insurgent forces in South Vietnam and on guerrilla battlefields of the future. Night air operations will play an increasing role in these battles by virtue of their inherent mobility and firepower, but firm doctrine and

finite tactics and techniques must be developed before the full impact of night air operations can be brought to bear. It is to this end that this thesis is directed.

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CHAPTER I

NIGHT, THE IMPARTIAL ENEMY

As a prerequisite to examination of factors which indicate evolving doctrine in the field of night air operations, it is necessary to examine some of the basic physical and psychological factors which affect any military activity at night. It is important to recognize that natural hazards associated with operations in darkness apply equally to foe as well as to friend. No human is immune to physical consequences which result when the ability to see is either hindered or completely obstructed. Night, therefore, is the universal enemy, the impartial enemy.

On the Ground

Although the United States Army considers that movement, attack, exploitation, and defense at night are routine operations, the Army also recognizes the fact that night combat is characterized by a decrease in the effectiveness of aimed fire.[1] The primary handicap of combat at night is reduction in ability to see. Without light, when the blackness of a moonless, starless night descends on a soldier in the field, he becomes a less useful tool in the hands of his leader. No matter the power of the weapon he carries, its unaimed might cannot

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[1] U. S. Department of the Army Field Manual 61-100, The Division (Washington, D. C.: U. S. Department of the Army, Jan 1962 and Change 1, 27 Mar 63), p. 119.

[redacted]

bring victory. This inability to see, manifests itself in at least five elements which influence, and normally degrade, the ground soldier's capability to perform his mission. These factors are the psychological impact of darkness, impaired mobility, susceptibility to injury, tension and fatigue, and time prolongation per task.

Although the psychological impact of darkness may vary with the ethnic, social, and physical environment which fostered his growth, each man, to some degree, is afraid when he must rely on feel instead of sight to find his way. Morale of troops both friendly and enemy is highly sensitive to physical and psychological factors.[2] Unidentified sounds are magnified and take on ominous and perilous meanings. Silent movement, which is so often an enforced requirement of night movement, serves to heighten tension and anxiety. Emotionally the average soldier on a blacked-out battlefield walks a fine line between severe apprehension and panic; a condition which can be miraculously alleviated by addition of just a pinpoint of sight and sense orienting light. There is a "tremendous morale factor inherent in being able to see at night."[3]

Individual movement and mass mobility suffer together under conditions of darkness. The slow measure step of the foot soldier, egg shell walking his way through the jungle, or the balcked-out column of vehicles snaking their way turtle-like down a hostile road

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[2] Ibid

[3] U. S. Army Command and General Staff College, "Battlefield Illumination Study," Informal Study: Operational Doctrine for Employment of Battlefield Illumination during the period 1960-1970 (Fort Leavenworth, Kansas: U. S. Army Command and General Staff College, 10 Feb 60), p. 7.

are the penalties of movement at night--penalties which infrared, image intensification devices, and luminescent paints can only partially attenuate. Without visible light, all of the basic employments of ground military forces cease or are seriously hindered. Penetration, encirclement, pursuit, exploitation; all become impossible or impractical when men cannot see. United States Army Field Manuals include numerous references to problems of night movement and, more specifically, night jungle movement.

> Effective movement and control at night is predicated on prior reconnaissance, stealth and silence in moving, close physical contact between individuals, and maximum use of navigational aids (compass, luminous disks and jungle matter, white material attached to equipment, use of engineer tape and/or telephone wire). In a tactical movement, a commander must insure slow movement, close formation, frequent halts to check formation and number of men, and use of spacing and the compass.[4]

> Night marches are characterized by closed formations, more difficult control and reconnaissance, and slower rate of march. . . . Difficulty of control requires more detailed planning; stringent control measures; thorough training; and enforcement of march, light, and communication discipline.[5]

> Time and space factors are carefully considered when planning the raid operation. Sufficient time is allowed for assembly and movement, particularly during darkness.[6]

> Ambushes conducted during periods of low visibility offer a wider choice of positions and better opportunities to surprise and confuse the enemy than daylight ambushes. However, control and movement to and during night ambush is more difficult.[7]

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[4]U. S. Department of the Army Field Manual 31-30, Jungle Operations (Washington, D. C.: U. S. Department of the Army, Oct 60), pp. 70-71.

[5]U. S. Department of the Army Field Manual 21-18, Foot Marches (Washington, D. C.: U. S. Department of the Army, Nov 62), p. 4.

[6]U. S. Department of the Army Field Manual 31-21, Guerrilla Warfare and Special Forces Operations (Washington, D. C.: U. S. Department of the Army, Sep 61), p. 116.

[7]*Ibid.*, p. 124.

The Senior advisor to the ARVN 25th Infantry Division made this observation in a discussion of Viet Cong movement tactics:

> VC conduct combat operations at night and the last phase of movement to combat at night. However, in 'safe' areas, VC move during both day and night. Jungles and mountain trails are difficult to navigate at any time especially at night.[8]

In consideration of the peculiar problems associated with jungle movement it is also important to recognize that "jungle terrain presents the same advantages and disadvantages to the enemy as it does the friendly forces."[9]

Hand in hand with the problem of night movement goes an increased susceptibility to injury. Each year in the United States, thousands of people injure themselves while attempting to navigate darkened stairways in the familiar surroundings of their own homes. Transfer implications of this familiar hazard to the untraveled and unfriendly terrain of a night battlefield, particularly a forested or jungle battlefield, and predictable casualties become a major planning consideration. The sprained ankle, a twisted knee, the brush-torn face and bleeding shin bone: individually, minor problems, but collectively, they spell the difference between a fully effective combat force and one which may wither under minor adversity when the battle is joined. Accidental injury and death due to non-combat causes will always plague the military commander. Therefore, it is with some reservation that a military leader accepts the certain increases in non-combat casualties

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[8]Office of the Director Advanced Research Projects Agency, Field Unit, Vietnam and Joint Operation Evaluation Group, Vietnam, "Evaluation of Test Results of the Employment of OV-1 (Mohawk) Aircraft in Support of Counterinsurgency Operations" (Saigon, Vietnam: Office of the Director Advanced Research Projects Agency, Field Unit, Vietnam and Joint Operation Evaluation Group, Vietnam, 19 Jul 63), Annex 7, p. 3.

[9]FM 31-30, op. cit., p. 68.

associated with night operations. Factors which dictate his decision to fight at night must override expected loss of combat power due to injuries incurred in movement to the place of battle.

Fatigue is a product of all military movement whether it be by foot or vehicle. Night movement, with its added psychological and physical hazards is even more fatiguing; and when a streaming jungle environment is added to the picture, fatigue become a major consideration.

> The execution of a raid that will require a deep penetration into the jungle will be affected by the physical endurance required of the men to traverse the jungle terrain.[10]
>
> To get troops to the proper place at the proper time in condition to successfully accomplish the mission requires the utmost in ingenuity and leadership of the commander.[11]
>
> The heat and humidity are factors which will affect every march to an unpredictable extent.[12]
>
> The extreme fatigue resulting from jungle marching is apt to cause soldiers to neglect to wash their clothes and bodies even though they have been told their health depends on cleanliness.[13]

Again, these are but a few of many references contained in United States Army Field Manuals which allude to the problem of physical fatigue. This problem is closely related to the previously discussed psychological problem. Performance of the simplest task under conditions of fear or anxiety, particularly when bodily injury is an ever-present possibility, is a debilitating, energy consuming strain. From personal experience, it is not uncommon for an all-weather interceptor pilot, on a night low-level intercept mission far at sea, to

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[10] Ibid., p. 67.

[11] Ibid., p. 38.

[12] Ibid.

[13] Ibid., p. 122

lose several pounds in an hours flight. This, under conditions of very little actual physical activity. Mental fatigue problems of a man carrying a back pack through jungle at night, with every step the prelude to a foot trap, booby trap grenade, or land mine, are even more critical. Compound this problem with the ofttimes enemy enforced sleeplessness of daylight hours, and man soon reaches the limit of endurance. There were many in Vietnam who ridiculed use of supersonic aircraft for sonic booming Viet Cong jungle bases. But if the enemy moves and fights at night he must sleep during the day, and there are few weapons as cheap as the sleep-disturbing sound of a sonic boom. Supersonic flight for short periods should be part of every daytime training or combat mission flown by jet aircraft over VC dominated portions of South Vietnam.

Time is the final factor considered in our discussion of night operations on the ground; and perhaps this is the most important of all the factors. It is possible to predict with some degree of accuracy the time it will take a man or a group of men to perform a given task during daylight. With intensive training, there are tasks which men can do blindfolded with almost as much efficiency as with open eyes. However, the large majority of tasks which a military man must perform in the discharge of his everyday duties, normally will take a longer period of time under conditions of darkness. This prolongation of time per task is a difficult thing to predict. It will vary with each task, being partially dependent on the number of other individuals who are involved, and on the degree to which these other individuals are involved with still another set of tasks. Because this thesis is oriented on the problem of night counterinsurgency operations

in Vietnam, and in cognizance of the jungle environment which characterizes a large part of that conflict, it is disturbing to note the lack of *specific* planning factors guidance in United States Army Field Manuals on the subject of movement of guerrilla or counterguerrilla land forces at night. Generalities are the rule. FM 31-30, *Jungle Operations*, says, "do not attempt to travel at night unless necessary."[14] "Movement in the jungle is calculated in terms of time rather than distance."[15] "Night movement is characterized by slow and deliberate progress and it requires detailed planning."[16] "In the jungle, time factors will be increased and space factors decreased."[17] Field Manual 21-18, *Foot Marches*, has this to say: "Because of the difficulties caused by reduced visibility and less effective control and coordination procedures, the rate of march is reduced over that normally prescribed for day marches."[18] "Movement in many areas of the world, must be calculated in terms of time rather than distance. The problem is *how long* it will take to get from one place to the other rather than *how many kilometers* it is between places. This is especially applicable in northern, mountain, or *jungle areas* [underlining mine] where trails are either limited or nonexistent, and cross-country movement may be slow and difficult."[19]

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[14] *Ibid.*, p. 33.

[15] *Ibid.*, p. 37.

[16] *Ibid.*, p. 42.

[17] *Ibid.*, p. 50.

[18] FM 21-18, *op. cit.*, p. 19.

[19] *Ibid.*, p. 6.

Perhaps it suffices to say that time is a problem and make no attempt to define how much of a problem, however, it is hoped that experience being gained by United States personnel in the jungles of Vietnam will be exploited more fully in future Army publications dealing with night ground operations in that type of environment.

We have covered briefly the more important military aspects (primarily limitations) of night operations on the ground. Now, let us examine these factors and others which have a peculiar relationship to operations in the air, and which serve to limit or hinder the airman's capabilities during darkness.

In the Air

> The first long-range strategic strike in history came in November 1914, when the British daringly sent three Avro 504's to bomb the Zeppelin sheds at Friedrichshafen, on Lake Constance in southern Germany. Little damage was done to the Zeppelin base and one of the British planes was downed, but the surprised Germans retaliated by forming a bombing squadron which they called the 'Ostend Carrier Pigeons.' By January, 1915, they were raiding Dunkirk, France, behind the Allied line, flying in formation and--surprisingly--flying at night.[20]

"Surprisingly--flying at night." Why surprisingly? It is sometimes assumed, and perhaps rightly so, that doing anything at night which can be done during daytime (except sleeping) is really quite unusual, unnatural, and unnecessary. Therefore it is really not surprising to see the "surprising" reaction to night flying, and particularly so when this flying included the act of dropping bombs on people. However, since man is the unconventional mechanism that he is, there was a certain inevitability to flight at night and subsequent use of the dark night sky to cloak operations of military aviators. But what

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[20]Alvin M. Josephy, Jr. _et al._, _The American Heritage History of Flight_ (New York: American Heritage Publishing Co., Inc., 1962), p. 161.

are some of the factors which make night an impartial enemy to pilots as well as to ground-bound soldiers?

There are psychological, physiological, mechanical, and natural phenomena which act to the detriment of a pilot at night.

We have touched briefly on psychological effects of night flight. A more detailed investigation reveals several additional psychological derivatives of flight in darkness. Leaving the firm and familiar environment of the ground for the unknown and unseeable atmosphere of a black night may forever have something of an unsettling effect on most men. The ability to orient oneself to nothing more tangible than the suspect needles of several dimly lit instrument dials establishes a tenuously balanced mental condition which extensive training can only partially assuage. Although difficult to establish statistically, it is the author's firm belief that the average pilot approaches night flying with somewhat less enthusiasm than he does day flying. The psychological barrier of darkness is an inborn and deeply rooted influence in the minds of men, and regardless of demands of the man on the ground who needs night air support, pilots are only men. Speed and darkness are also strange bedfellows. The knowledge that you may be rushing headlong toward some other animate object, hidden in the darkness but no less disastrous in its collision effect, serves to keep ones attention and concentration at an extremely high level and reduces to some unmeasured degree ones combat effectiveness.

Pilots who participated in a suitability test in 1954 to determine a fighter-bomber squadron's capability for night tactical air operations were unanimous in their appreciation of moonlight and/or artificial

light to assist them in performing their night missions.[21] This appreciation can be attributed to more than improvement in target acquisition and ordnance delivery capabilities. It was also undoubtedly due to the simple ability to see where they were going.

There are several physiological characteristics of man which tend to reduce his capability to function efficiently at night in the air. These characteristics also affect man during day flying but to a lesser degree. The first and most important is vision. Without becoming overly technical, it will suffice to say that visual acuity is reduced in direct proportion to the amount of light which enters the eye. Ability to distinguish detailed features of an object at a given distance decreases as light on that object is reduced. As ability to distinguish detail diminishes so does ability to determine distance to the object. Depth perception is therefore a correlative of available light.[22] Loss of depth perception is one of the effects which a pilot experiences at night and which affects his combat capability. Another effect which, particularly in a combat environment, can derogate a night-flyer's capability, is loss of dark adaptation. Once the eye becomes adjusted to darkness it does a relatively good job of seeing, even under conditions of extreme light reduction. However, sudden exposure of the eye to bright light can instantly destroy this adaptation with resultant reduction and, in extreme cases, complete loss of ability to see at night. A pilot's visual orientation on a

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[21] Air Proving Ground Command, "Final Report on the Operational Suitability Test of a Fighter-Bomber Squadron for Night Tactical Air Attack," Project No. APG/TAT/128-A (Eglin Air Force Base, Florida: Air Proving Ground Command, 27 Dec 54), p. 19.

[22] S. L. Poyak, M.D., "Eye, Human," <u>Encyclopaedia Britannica</u>, 14th ed. (1954), IX, 5-8.

burning target at night reduces his dark adaptation to the extent that he must resort to instrument flying when he passes beyond the light emanating from the fire. This transition from contact to instrument flying is a breeding ground for a third physiological effect on the night pilot, i.e., "vertigo." Vertigo is caused by false signals generated in the inner ear which lead a pilot to believe his aircraft is in an attitude other than its actual attitude. Without a visual form of reference, reaction to the false signal can cause a pilot to fly his aircraft into a position from which he may be unable to recover. This is particularly hazardous on a night close support mission at low altitudes. There are, of course, other physiological effects which, under certain conditions, may degrade a pilots capability at night, such as carbon monoxide poisoning or lack of oxygen, either of which reduce the ability to see. Loss of color vision which occurs under conditions of reduced light also contributes to a reduction in target acquisition facility. Taken as a group, the physiological characteristics of man in a night flying environment are definitely a degrading factor, but not to the extent that man cannot effectively perform a variety of night combat missions.

Mechanical problems encountered in night air operations could perhaps be more aptly described as support and tactical problems. Aircraft which fly at night frequently must be serviced at night, loaded with ordnance at night, and, in many cases, maintenance must be performed at night. Cockpit instruments and instrument lights plus navigation and landing lights take on a new importance for both pilots and maintenance and supply people. In this regard, factors which affect Army/night operations on the ground apply equally to ground support

elements of air forces. It takes more time to do things at night. The hazards of loading ammunition are greater at night. Maintenance areas must be lighted. More people are injured on the flightline at night. Runway and ramp lights and navigational aids must be maintained in peak condition. In addition to these purely physical and technical problems on the ground, a pilot is faced with certain tactical problems in flight which could be defined as mechanical in nature. The mechanics of flying formation at night are somewhat different than during daytime. Formation join-up and separation during the attack are maneuvers which pilots do routinely during daylight. At night, however, special briefing and, of more importance, special training and psychological adaptation is required if these maneuvers are to be performed with confidence and safety.

As a prelude to the suitability test mentioned previously, Air Proving Ground Command conducted a test project to determine tactics and techniques for night tactical air attack. In the collective analysis of this project it was concluded that "psychological adaptation of the day fighter pilot to night operations was the most important of the problems encountered."[23] Twenty hours of intensive night training was considered a minimum for this adaptation.[24] The test project conclusions were stated as follows (each of these conclusions, with the exception of "b" have mechanical implications):

a. That pilots are thoroughly trained and indoctrinated prior to attempting to perform night tactical air attack operations.

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[23]Air Proving Ground Command, "Final Report on Fighter-Bomber Tactics and Techniques for Night Tactical Air Attack," Project No. APG/TAT/22-A-8 (Eglin Air Force Base, Florida: Air Proving Ground Command, 1 Jul 54), p. 20.

[24]*Ibid.*, p. 21.

b. That weather and visibility conditions are not too adverse.
c. That some means for illuminating the target is provided.
d. That suitable means and procedures exist for navigation, tactical control, and recovery for fighter-bomber type aircraft.
e. That steps are taken to improve the cockpit lighting so that pilot's visibility from the aircraft may be more efficient.[25]

The mechanical problems of night air operations are unavoidable. Nevertheless, they constitute one aspect of the battle with our enemy, night, in which we can be assured of partial victory through the medium of training, research, and development.

A final factor or phenomena considered as having a detrimental effect on night air operations concerns those "natural" aspects of night which create problems for a pilot. These are simply manifestations of a pilot's inability to see, and therefore, could be classified as physiological in nature. However, it is in consideration of the long-range implications of reduced visibility that we examine the problem. Night plays its most important role as adversary of airmen by hiding and disguising targets which during the day are easily distinguishable by shade and shadow contrasts. When night lays its mantle of darkness over the land, the only contrast visible to a pilot's unaided eye is provided by man-made points of fire-light against the black background of the earth or the heavenly points of starlight against the blackness of the sky. On a clear night these points of light often merge at the horizon to give a pilot an "inside-of-the-fishbowl" feeling and the beginnings of vertigo. To locate a target area on a night such as this without some aid from an external source is, at the outset, a difficult task. To positively identify a point target within that area without aid of some form of artificial or natural illumination is next to impossible: to attempt accurate delivery of

[25] Ibid., p. 8.

ordnance on that target under such conditions is folly. Add the efforts of a military target to further camouflage itself by taking advantage of the deepest ravine and the most impenetrable forest, and the handicap of darkness becomes insurmountable to a searching pilot. The final report of the Army/Air Force Close Air Support Board painted a slightly more optimistic picture.

> A well trained and highly disciplined enemy can, by use of various tactics, make it extremely difficult to spot small number of personnel on the ground from an aircraft at night . . . It can be expected that the greatest degradation at night will be in the inability to acquire personnel targets.[26]

It is also significant to note the Board's conclusion that "tests and operational experience have shown that night delivery accuracy is not significantly degraded provided the pilot can acquire the target."[27] The overall degradation of night close air support is due primarily to problems in target acquisition. The figures quoted in the Board report reflected a 30 per cent reduction in target acquisition capability at night, versus a 10 per cent degradation during daylight.[28] However, these figures appear overly optimistic when cast in the environment in which flareship and night strike pilots have found themselves in Vietnam during the past two years.

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[26] U. S. Army - U. S. Air Force Close Air Support Boards, "Joint Final Report U. S. Army - U. S. Air Force Close Air Support Boards" (Fort George G. Meade, Maryland: Office of the Adjutant General, Headquarters Second United States Army, Initial Edition, Vol. IV, Aug 63), Tab S to App. 3 to Annex F.

[27] Ibid., App. 3 to Annex F, p. 8.

[28] Ibid., Tab S, App. 3, Annex F.

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In Vietnam

Early in 1962, the one aspect of the military effort in Vietnam which made the greatest impression on newly arrived American Army and Air Force advisors was the "banking-hours" approach which the Vietnamese took toward fighting communist insurgents. From 0800 until noon and from 1500 until 1700 the counterpart program functioned as well as could be expected considering language problems. However, during the three hour afternoon siesta period, and the remaining hours of the day and night, advisors could only give advice to each other and hope that the Viet Cong would oblige by forestalling aggression until the ARVN was on duty and the VNAF was ready to fly. Patterns of Vietnamese activity born of eight years battle with the insurgents were difficult to change; and, in fact, after three years exposure to the animated and sometimes overanxious American advisor, these patterns, to a large extent, still remain. The Philippines' Reserve Officers Legion, in commenting on the status of the war in Vietnam and the increasing Asian involvement, was quoted by the Baltimore Sun on 15 December 1964 as saying:

> It is also quite evident, that the rush-rush-rush nature of the American way of doing things simply is far out of mesh with the slow and deliberate Asian way of getting things done.[29]

The regular Republic of Vietnam Armed Forces (RVNAF) soldier or airman has demonstrated a not too abnormal reaction to battle at night, i.e., avoid it if possible. General Guenther Blumentritt made this observation:

> It is interesting to note in the 'history of night battles' that well disciplined, regular troops have always been very reluctant to expose themselves to the hazards of darkness, while on the

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[29]Associated Press News Release, "Fillipinos For Backing Their Viet Forces," Baltimore Sun, 15 Dec 64.

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other hand, less civilized nations and those taking part in 'illegal warfare' actually welcomed night as their ally. Colonial, Indian, and similar wars prove this statement, and it is due to this fact that in these semi-civilized wars the well-organized, regular troops were often wiped out by the irregulars and the 'close-to-nature' fighters.[30]

Anyone who has been directly exposed to the war in Vietnam cannot, with honesty, say that there has been any significant effort made by the Government of Viet Nam (GVN) toward changing the pattern of conflict to meet the enemy on his own ground. Battle tactics have changed to some degree, and mobility has certainly been emphasized almost ad nauseam, but the fundamental approach to the problem of meeting the enemy with appropriate forces and weapons on terrain of our choosing <u>and at a time of our choosing</u> has been either ignored or enjoyed only token consideration by Vietnamese military leaders. The limited night capability of the RVNAF has been utilized almost exclusively in a reaction role.

We must also admit that the American Army and Air Force advisors cannot be completely exonerated from responsibility for the lack of emphasis on night operations. We too, fall into the category of "well disciplined, regular troops who are reluctant to fight at night." The unending parade of daytime "clear and hold" and "search and destroy" operations involving massive numbers of helicopters and armored personnel carriers with barrages of supporting artillery, too often yield very little, if any, results and are typical of the "big war" thinking and planning which seems to permeate this "little war" theatre.

Although we recognize that the apparent tenor of the war is

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[30]Guenther Blumentritt, General der Infanterie a.D., "Operations in Darkness and Smoke," Manuscript No. B-683, Trans. A. Schroeder, Ed. H. Hertman, Originally prepared by Historical Division European Command, Foreign Military Studies Branch (Washington, D. C.: Office of the Chief of Military History, Department of the Army, 1952), p. 3.

now slowly beginning to develop along more conventional lines, it is indeed unfortunate that proper emphasis on unconventional tactics was not applied in the beginning. Results of such emphasis might well have prevented, or at least curtailed, the escalation which has taken place during the final months of 1964 and early months of 1965.

Although night is purportedly an impartial enemy to both friend and foe, in Vietnam, night has been a partial enemy to the GVN forces, primarily due to their unwillingness to accept night as a normal and, in fact, a desirable battle environment, and to conduct their operations accordingly. The rain-forests and flooded rice paddies of Vietnam present obstacles to night operations which should not be minimized in their impact; and the problem of visually acquiring and attacking the typical Viet Cong ambush or patrol party from the air at night is certainly complicated by the peculiar environment with which we are faced in that country. However, this is the environment and these are the conditions with which we may be faced in still unnamed countries for generations to come. Night must cease to be an enemy. Night must become the ally.

CHAPTER II

NIGHT, THE ALLY EXPLOITED

Evidence which supports the thesis that "night is an enemy," is interestingly ambiguous. Factors which have a detrimental effect on military operations at night may also be applied to favor these operations and, in fact, the body of military history aligns itself more strongly behind night as a military ally than it does the converse. We therefore turn to documentation of the opposite thesis, "night, the ally," and to a discussion of its exploitation.

On the Ground

What are factors which favor the use of darkness as an ally to a soldier on the ground? Cover, concealment, secrecy, and surprise are among the more obvious elements. Less obvious, but not of less importance as factors, particularly in the jungle, are temperature and humidity.

The Dictionary of United States Army Terms defines cover as "shelter or protection, either natural or artificial. See also concealment."[1] Concealment is defined as "the protection from observation only. See also cover."[2] These two terms are basically synonymous, and in a discussion of night operations their meanings become

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[1]Headquarters, Department of the Army, Army Regulation 320-5, Dictionary of United States Army Terms (Washington, D. C.: Headquarters, Department of the Army, 28 Feb 63), p. 104.

[2]Ibid., p. 116.

even more closely related. The natural shelter or protection afforded by darkness is a consequence of restricted observation. An infantry or tank platoon deployed on open terrain is sheltered and protected by the concealment of darkness just as effectively as if under cover of bunkers or heavy foliage. If we combine the artificial cover of bunkers and the natural cover of heavy foliage with the added concealment inherent in darkness, the overall benefits accruing to a military force present a significant advantage. Under "cover" of darkness--an interesting cliche in view of this discussion--a foot soldier or tank commander acquires freedom of action in and around his artificial or natural cover; a freedom that permits activity which is impossible or at best extremely risky during daylight. Minefields can be laid, gun emplacements prepared, forces deployed, and offensive or defensive positions solidified; all with relative impunity. U. S. Army Field Manual 61-100 states that troop movements, concentration of forces prior to attack, and conduct of an attack which may be impossible during daylight may be executed in darkness with minimum risk.[3] At the lower end of the combat scale, in guerrilla operations, it is reasonable to conclude that the benefits of night operations are still more telling.

> Guerrilla tactics are primarily small unit, infantry-type tactics which make full use of accurate intelligence, detailed planning and rehearsal, simple techniques of maneuver, speed, surprise, infiltration, specialization in night operations, and the undermining of enemy morale. . . . By specializing in night operations, a guerrilla force effectively reduces its vulnerability to air and artillery attack.[4]

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[3]U. S. Department of the Army Field Manual 61-100, The Division (Washington, D. C.: U. S. Department of the Army, Jan 62 and Change 1, 27 Mar 63), p. 119.

[4]U. S. Department of the Army Field Manual 31-15, Operations Against Irregular Forces (Washington, D. C.: U. S. Department of the Army, May 61), p. 9.

[redacted]

> The magnitude and effectiveness of the probable enemy combat forces to be defeated will vary from scattered guerrillas to organized combat units built around or supported by large numbers of armored combat vehicles, artillery, and close support aircraft. The opposition at the lower end of this spectrum will favor night operations and movement in the face of our superior firepower.[5]

This last precept has been amply substantiated in South Vietnam.

> The majority of Viet Cong activity takes place at night. Based upon reports from other intelligence means, it is suspected that the Viet Cong conduct relatively large movements in the open along roads and waterways during the hours of darkness.[6]

The U. S. Marine Corps Tactics and Techniques Board concluded that "Soviet, Chinese, and numerous communist-oriented guerrilla organizations have clearly indicated a military awareness of operations at night and during other periods of low visibility."[7]

The increasing exploitation of darkness by the enemy dictates an increased counter-effort to limit this exploitation. To this date the effort has been insufficient to give true meaning to our military operations at night.

Secrecy and surprise are fundamentals of combat. The ability to achieve these fundamental combat objectives by using night movement and attack has been demonstrated repeatedly throughout military history. In more recent history, limited or insurgent war has become increasingly night oriented. Darkness has been exploited to the maximum by

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[5]U. S. Marine Corps, "Aids for Close Combat at Night," General Operational Requirement No. CT-4 (Washington, D. C.: Department of the Navy, Headquarters U. S. Marine Corps, 25 Sep 63), p. 1.

[6]U. S. Army Concept Team, Vietnam, "Mohawk Aircraft in the Target Acquisition Role" (Saigon, Vietnam: U. S. Army Concept Team, Vietnam, 1 Feb 64), App. 2, Annex A, p. A-22.

[7]Marine Corps Landing Force Development Center, "Concept of Close Combat During Night Operations and Other Conditions of Low Visibility," Report of Project No. 30-61-10, Conducted by Tactics and Techniques Board (Quantico, Virginia: Marine Corps Landing Force Development Center, 31 Dec 62), p. 4.

guerrilla bands who have recognized the value of night operations to maintain secrecy and to achieve surprise. General Blumentritt observed that "small, well composed combat parties are frequently apt to achieve more during night operations than big mass formations. The effectiveness of such combat groups, far in the rear of the surprised enemy, is usually far more than their actual striking power."[8] A Rand report concluded that "tactically, despite their military inferiority, the insurgents are usually on the offensive, making use of surprise and local superiority in raids, ambushes, and harassing actions."[9] These operations have been conducted predominantly at night for several reasons. The relatively slow and often disorganized reactions of a watchful but sleeping outpost to a well planned and swiftly executed surprise attack will, in most cases, result in heavy casualties to the defenders and probable victory to the attacker. The night ambush is another tactic which capitalizes on defensive confusion with its resultant ineffective counter-fire. A variation of this tactic is the late afternoon ambush in which the guerrilla uses the waning light of day to inflict maximum damage on the ambushed force and then melts into the gathering shadows of dusk.

United States Army doctrine for employment of the division in night combat recognizes that night operations which achieve surprise may offer opportunities for success when daylight operations are

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[8]Blumentritt, Guenther, General der Infanterie a.D., "Operations in Darkness and Smoke," Manuscript No. B-683, Trans. A. Schroeder, Ed. H. Hertman, Originally prepared by Historical Division European Command, Foreign Military Studies Branch (Washington, D. C.: Office of the Chief of Military History, Department of the Army, 1952), p. 22.

[9]H. Speier et al., "Counter-Insurgency and Air Power: Report of a Rand Ad Hoc Group," Memorandum RM-3203-PR (Santa Monica, California: The Rand Corporation, Jun. 62), Preface, p. vii.

impracticable. The concept of maintaining continuous pressure on the enemy, day and night, is also stressed.[10] Deception is a factor mentioned in FM 100-5. "Night attacks and night movement are normal operations that offer an excellent opportunity for deception and surprise."[11] Army doctrine also emphasizes employment of counterguerrilla or Special Forces units in night operations to achieve surprise.

> The requirements of the situation determine whether movement and attack should be made during daylight or darkness. Darkness favors surprise and is usually the best time when the operation is simple and the physical arrangement of the installation is well known.[12]

Closely related to previously discussed factors of cover, concealment, and surprise is secrecy. In insurgent dominated areas, the local population is normally reluctant to provide intelligence information to counterinsurgency forces and in many instances they actually provide cover and concealment to the enemy, simply to survive. The terrorized population becomes the unwilling participant in a vast network designed by the insurgent to provide secrecy for his own movement, early warning of approaching government forces, and refuge for the detached fugitive.

A reduction in heat and humidity is the final factor which night gives as a gift to the foot soldier. "Night marches are characterized by . . . better concealment from hostile observation and air attack. In addition to providing better concealment for movement,

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[10]FM 61-100, _op. cit._, p. 119.

[11]U. S. Department of the Army Field Manual 100-5, _Field Service Regulations - Operations_ (Washington, D.C.: U. S. Department of the Army, 19 Feb 62 and Change 1, 7 Feb 64), p. 66.

[12]U. S. Department of the Army Field Manual 31-21, _Guerrilla Warfare and Special Forces Operations_ (Washington, D. C.: U. S. Department of the Army, Sep 61), p. 116.

night marches may be made to avoid excessive heat and to exploit the darkness and achieve surprise."[13] In a desert or tropical setting, excessive heat is an assumed and accepted factor which degrades operations of men and machines alike. In tropical jungle, high relative humidity adds to the already demoralizing heat effect. Although nightfall brings only partial relief from the sticky, bug-infested dampness of the jungle floor, the usual drop in temperature associated with twilight will forever be a welcome relief to the jungle fighter. The traditional siesta period, so characteristic of tropical and subtropical countries, is a natural and perhaps necessary manifestation of man's inability or unwillingness to do manual tasks when air temperature exceeds body temperature. When, in addition, the air is moisture laden to the point of saturation, man's rebellion is complete.

The advantages of night operations on the ground are easily identified and significant, however, emphasis on exploitation of these advantages has been less than desirable. Unfortunately, emphasis on night air operations has been no greater, and the advantages in that environment are perhaps more significant.

In the Air

Five factors which serve to make night an ally of the soldier on the ground apply equally to airborne combatants. Cover, concealment, secrecy, surprise, and temperature--all of these affect the successful employment of air power, particularly in counterinsurgency operations.

In the typical insurgency/counterinsurgency operation, aircraft are exposed to ground fire not only during the attack or operational phases of their missions but also during the airfield departure and

[13] U. S. Depart[redacted]d Manual 21-18, Foot Marches (Washington, D. C.: U[redacted]y, Nov 62), p. 4.

recovery phase. The insurgent, armed only with a small caliber rifle, and positioned beneath the traffic pattern of selected airfields, can inflict light to moderate (and sometimes severe) damage on slow moving aircraft, taxiing, landing, or taking-off. To minimize this hazard, the airmen may well be forced to utilize darkness as an ally.

Darkness provides protective cover and concealment for aircraft during all phases of night air operations. From departure, through enroute, attack, or assault landing, and recovery phases, the pilot and his machine are wrapped in a heavy armor plate of obscurity. The ever-present sniper on an airfield or landing zone perimeter and the insurgent who becomes target-for-tonight must rely predominantly on the relatively inaccurate sense of sound to direct his fire or counterfire. Concealment from observation provided by night becomes protective cover for the pilot, his cargo, his passengers, and his plane.

The night flyer also benefits by the natural secrecy which shrouds his departures and arrivals during darkness. Well organized insurgents are able to monitor daylight air operations emanating from the relatively few major airfields and pass warnings of possible attack through the jungle grapevine to their comrades hiding in the surrounding country-side. From a vantage point or points, the number and direction of flight of helicopters, fighter-bombers, and troop carrying transports can be determined with ease. With this knowledge, the forewarned insurgent reacts accordingly, and one more "search and destroy" operation bears little fruit. Determining the direction of flight of an aircraft at night, however, is a difficult job even for the trained observer. Without being able to visually acquire an airborne object, the insurgent can only guess at its intentions. The

advantage shifts to the now secretly employed attacker and surprise re-enters the picture.

In a target or landing zone area at night, the element of surprise is further expanded due to enemy difficulty in determining the direction from which the next strafing or bombing attack will come. His inability to observe the pattern of helicopter deployment and of air landed troops once they are on the ground also contributes to surprise. Due to the speed of modern aircraft and helicopters, surprise is always inherent in their employment. Darkness adds an additional facet to the innate ability of an airborne weapon or soldier to surprise an adversary.

Heat and humidity have an adverse effect on pilots and crewmembers which is often equal in impact to its effect on ground forces. This is particularly true in close air support operations and "knap-of-the-earth" flight by helicopters. Although modern jet aircraft have highly effective cockpit heating and cooling systems, when low altitude operations in tropical climates are conducted, the humidity is usually so high that introduction of cooling air into a cockpit can cause fog thick enough to blind the pilot. Conventional aircraft and helicopter pilots do not enjoy the luxury of refrigerated air even if it could be used without clouding the cockpit. Therefore, airmen are forced to perform their highly complex and exacting tasks while bathed in their own energy consuming sweat. Several missions flown in quick succession under these conditions may seriously impair the capability of an airman to perform his duties with maximum efficiency. During fighter-gunnery training at Nellis Air Force Base in the staggering heat of a July day, the author experienced this reduction in efficiency on many occasions after flying several low-level strafing

missions. The green flying suit turns white with the excreted salt of your body, and beer and bed become the only panaceas.

What is one answer to this problem? "Flying in the coolness of the night" is admittedly an over simplified solution, nevertheless, it is one worthy of serious consideration. In consideration of all other factors which affect flight at night, avoiding excessive heat and humidity becomes an important addition to the list.

There are still other elements which favor night air operations. In general, with the coming of darkness, weather conditions begin to improve. The afternoon thunderstorms, so characteristic of countries under the influence of a monsoonal climate, dissipate by mid-evening.[14] The sky clears and instability of the daytime air gives way to smooth and stable air of the night. The aircraft, as a weapon platform, becomes more manageable, and the illuminated target remains steady in the sight-picture of the diving fighter-bomber. Cool night air also becomes more dense, and gusty winds of the day begin to diminish. Denser air gives helicopters more lifting power. Added lift combined with smoother air gives the pilot a margin of safety in his approaches to landing zones, or when hovering is required, that he doesn't enjoy during the hot and turbulent day. In a large scale operation this added lift capability might well result in increasing the airborne force by as much as an entire platoon (one additional soldier per aircraft).

In Chapter I, we discussed natural phenomena of the night which acted to impair the ability of the night flier to perform his mission. One of these was the simple inability to see clearly. It is interesting to note that this same phenomena can serve to aid the pilot

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[14] U. S. Army [redacted], op. cit., p. 6.

when properly exploited. The immediately discernible rays of a signal flashlight against the background of dark sky or terrain; the coded flashes of navigation lights to signal execution of a maneuver; the relatively easy acquisition of enemy campfires; and the muzzle flashes from enemy ground fire--these are but a few of the ways in which the contrast of light against darkness can be used to advantage by airmen at night. A pilot's ability to see many things is noticeably reduced at night; however, the sharp disparity between general darkness and light from a single candle is unmistakable.

It is apparent that while unfamiliar to some and possibly foreboding to others, night can become an ally to man in the air; an ally which, in the counterinsurgent wars of today and tomorrow, can and most definitely should be exploited to the maximum.

In Vietnam

How do we apply the thesis that "night is an ally" to the counterinsurgency battlefields of Southeast Asia? Is there anything special about Vietnam which makes night more or less an ally in that country?

Aside from the unique considerations of geography (or more specifically in this case, terrain and vegetation), night is as much an ally of the soldier or airman in Vietnam as it is in any other country. In the type of war being fought in Southeast Asia, night has been one of the dominant factors in a large majority of the military actions which have taken place. However, this is primarily due to actions of the Viet Cong and to emphasis which <u>they</u> have placed on night operations. This emphasis has been forced on the VC by the overwhelming (but not [redacted]) manpower and equipment

superiority of the United [redacted] forces. It is this fact, in itself, which makes our own emphasis on large scale movement of forces and employment of aircraft during daylight so difficult to understand. We entered the conflict late in 1961 with significant numbers of personnel and tons of supplies and equipment, already knowledgeable of the type of tactics which were being employed by the enemy. We chose to make and continue our buildup as a massive military effort along primarily traditional and conventional lines. It was as if every lesson learned in previous counterinsurgency efforts was a false lesson, and that we must prove that sophisticated and well equipped military forces could, in fact, defeat the barefooted insurgent strictly by weight of advanced American technology and properly guided indigenous personnel. The months and years since our military involvement began have only served to reinforce the old curriculum of how to fight the insurgent. It is the author's belief that the emphasis in the beginning, built on the grandiose scale that it was, and publicized as it was, resulted in keying the communist Viet Cong response, to an even greater degree, to reliance on darkness for all types of military and paramilitary operations. The oft quoted guerrilla tactics, "if the enemy attacks, 'disappear;' if he defends, 'harass;' and if he withdraws or at any time he is vulnerable, 'attack,'"[15] were being practiced to a fine art in Southeast Asia long before American forces arrived on the scene, and they will be practiced long after we withdraw. We could perhaps add one characteristic to the list of guerrilla tactics which would aptly describe their use in Vietnam, and that would be to "do all these things at night."

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[15] FM 31-15, op. cit., p. 9.

[redacted]

UNCLASSIFIED

Official records of the current conflict in Southeast Asia are replete with documentation of VC night attacks, ambushes, and harassments. A VC narrative of actions leading up to or supporting the Battle of Ap Bac on 2 January 1963 is indicative and typical of tactics and philosophy which have been used so successfully by the Viet Cong in exploiting darkness. The philosophy was expounded in the statement:

> We should make use of the factor of time and good opportunities to assist our main body in retaining the initiative. We should try to prolong the combat to make the enemy tired and then to easily exterminate him at nightfall.[16]

Various tactics used to exploit the night were expressed in the following details of the actions:

> For 2 successive nights, they led the people to beat drums, call propaganda meetings and sabotage Phu My Strategic Hamlet.
>
> . . . .
>
> At night, they penetrated Lam Son training center and Tan Hiep Street and killed 1 enemy and wounded another.
>
> . . . .
>
> On the night of 2 Jan 63, we harassed the Strategic Hamlet. . . . And on the night of 2 Jan 63 we harassed Thanh Phu Strategic Hamlet.
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> . . . .
>
> At night, the guerrillas from all 3 villages attacked Nhi Binh and Duong Dien Strategic Hamlets.
>
> . . . .
>
> On the night of 2 Jan 63, the same guerrillas and the Dong Hoa guerrillas led the people in attacking Vinh Kim and Dong Hoa Strategic Hamlets.
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> . . . .
>
> On the nights of 2 and 3 Jan 63, the guerrillas from the 3 above villages encircled Cho Cau Post (Long Thien) and attacked and harassed Hoa My Strategic Hamlet.
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> . . . .
>
> On the night of 2 Jan 63, our armed forces infiltrated into My Tho City and fired 2 rifle grenades at the base of the 2nd Armored Regiment.[17] [Underlining mine]

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[16] English Translation of Viet Cong Document, "Ap Bac Battle 2 January 1963," Prepared by Assistant Chief of Staff, J-2 (Saigon, Vietnam: U. S. Military Assistance Command, Vietnam, 20 Apr 63), p. 41.

[17] Ibid., p. 6.

The late aftern[redacted]ed previously and further demonstrates tactical use of night by the Viet Cong. The Military Assistance Command, Vietnam (MACV), reporting on operations during the week of 15 August 1964, cited an ambush of this kind and made the following comments:

> THE FACT THAT THE PURSUIT OPERATION WAS COMPLETED, AND THE ARVN UNITS WERE RETURNING TO THEIR BASE, AND WERE FATIGUED AFTER THE DAY'S OPERATIONS, MAY HAVE LED TO A LACK OF SECURITY. THIS, IF TRUE, IS AN INDICTMENT OF THE COMMANDERS, BECAUSE IT IS WELL KNOWN THAT THE DAYLIGHT HOURS FROM ABOUT 1630 ON ARE CRITICAL ONES FROM THE STANDPOINT OF VC AMBUSHES.[18]

The average "regular" soldier too often looks forward to nightfall as the welcome end of a hard day of conflict. This attitude can be disastrous in the face of an enemy which operates on the premise that night is a more advantageous environment for military engagements and surprise attack. The element of surprise used in conjunction with darkness or approaching darkness can be a decisive factor in military operations. Darkness serves to reinforce the already potent military fundamental of surprise.

In Vietnam, the secrecy inherent in night has been added to the insurgents' list of allied forces. "IN STRONGLY VC-DOMINATED DINH TUONG PROVINCE, A VC DOCUMENT WAS CAPTURED WHICH IS ALLEGEDLY A DIRECTIVE OF THE VC MILITARY HEADQUARTERS OF MY THO, ESTABLISHED A CURFEW FOR THAT AREA AND STRICTLY PROHIBITED THE PEOPLE FROM GOING OUT BETWEEN 1900 AND 0700 HOURS."[19] By restricting local population movement to daylight hours, the Viet Cong may maneuver at night with

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[18] U. S. Military Assistance Command, Vietnam, "Military Reports" (USMACV MILREPs, Published Weekly, 11 Mar 64 through 31 Jan 65, Saigon, Vietnam: U. S. Military Assistance Command, Vietnam), Week of 15 Aug 64, p. 9.

[19] *Ibid.*, MILREP Week of 18 Apr 64, p. 18.

little fear of detection by government agents. They are able to establish ambush or raid attack positions in complete secrecy. In addition, any movement by government forces can be easily detected and attacked or avoided as the situation dictates.

When the author first arrived in Vietnam, one of many Vietnamese military expressions which required definition was the term, "VC Secret Base." Small yellow or red cross-hatched blocks, from three to ten kilometers square, were carefully plotted on the G-2 situation maps and prominently displayed in the Corps Tactical Operations Center (CTOC). From the standpoint of an unindoctrinated Air Operations Officer, these areas initially appeared to be inviting targets for a concentrated program of interdiction. However, a more careful examination of the actual nature of these predominantly jungle "targets," from both an aerial photograph and visual reconnaissance view, soon uncovered the reason behind their designation as "Secret Bases." While the general area had been located on the basis of intelligence reports from defecting or captured VC, the exact location could not be pinpointed on a map to an accuracy of less than three to four square kilometers. With the "bomber" force available at that time, it was not considered feasible to attempt saturation bombing of such a large area. Inaccuracy of maps in this part of the world also contributed to the decision. The fact that the Viet Cong may conduct almost unrestricted day and night training and supply operations under cover of the twenty-four hour "darkness" of the jungle truly categorizes these locations as "Secret Bases." It would appear logical to assume, however, that this type of "target" would, in fact, be more susceptible to attack at night when infractions of light discipline,

born of a sense of security or complacency, would act to pin-point the exact target locations.

The weekly United States Military Assistance Command, Vietnam Military Reports further document the continued VC exploitations of night.

> AT 120100 APRIL, A STRONG VC FORCE SIMULTANEOUSLY ATTACKED VINH TAY OUTPOST . . . AND KIEN LONG DISTRICT HEADQUARTERS . . . IN CHUONG THIEN PROVINCE. . . . AT 120230 FLARESHIPS ARRIVED AND AT 120500 TWO STRIKE AIRCRAFT PROVIDED CLOSE SUPPORT: ONE BOMB LANDED DIRECTLY ON THE 105MM HOWITZER POSITION WHICH VC HAD TAKEN, SHORTLY AFTER DAYLIGHT, THE VC WITHDREW TO THE NORTHWEST.
>
> . . . .
>
> AT 2000 HOURS THE VC INITIATED A SERIES OF ASSAULTS AGAINST THE BN CO'S ELEMENT. THESE ASSAULTS OCCURRED AT TWO HOUR INTERVALS THROUGHOUT THE NIGHT AND WERE STOPPED JUST SHORT OF FRIENDLY DEFENSIVE POSITIONS.[20]
>
> EARLY ON THE MORNING OF 19 APRIL, IN AN APPARENTLY COORDINATED OPERATION, VC HARASSED THREE POSTS AND A TRAINING CENTER. . . . AN HOA TAY PCST, MANNED BY 59 SDC AND SUPPORTED BY ARTILLERY AND A FLARESHIP, BORE THE BRUNT OF THE VC ACTION.[21]

These reports also testify to general failure or reluctance of GVN forces to counter VC actions with offensive night operations of their own. An example is cited from the MACV Military Report of 28 March 1964:

> ALTHOUGH THE NUMBER OF OPERATIONS INITIATED PRIOR TO DAYLIGHT REMAINS AT THE LEVEL OF LAST WEEK, 17, NO VISIBLE IMPROVEMENT HAS BEEN NOTED IN PLANNED NIGHT OPERATIONS. THE ARVN STILL SHOWS A RELUCTANCE TO PLAN AND INITIATE LARGE SCALE NIGHT OPERATIONS. MACV IS MAKING STRONG REPRESENTATION TO INCREASE THE NUMBER OF NIGHT OPERATIONS IN ADDITION TO ENLARGING THE FRIENDLY FORCES INVOLVED. FAVORABLE RESULTS ARE BEING REALIZED FROM THOSE OPERATIONS THAT ARE INITIATED DURING THE HOURS OF DARKNESS.[22]

The MACV report of 11 April 1964 stated that "INDICATIONS ARE THAT THE HOURS OF DARKNESS ARE BEING USED BY THE RVN PRIMARILY FOR MOVEMENT TO THE OPERATIONAL AREA AND FOR MARSHALLING TROOPS. RATHER

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[20] _Ibid._, MILREP Week of 11 Apr 64, p. 6.

[21] _Ibid._, MILREP Week of 18 Apr 64, pp. 24-25.

[22] _Ibid._, MILREP Week of 28 Mar 64, p. 12.

THAN FOR ACTIVE OPERATIONS AGAINST THE VC.[23] It appears that although some progress is being made to exploit darkness, it is still difficult for American advisors to instill in their counterparts the willingness or desire to achieve the full benefit of well planned offensive operations utilizing this ally, night.

Emphasis must not be any less on exploitation of night <u>air</u> operations than on ground operations. In fact, there appears to be some basis to the contention that <u>night</u> air operations, if properly planned and executed, can be conducted more safely and be more effective in inflicting casualties on the Viet Cong than day air operations.

The hazard to air operations on and near terminal facilities was cited previously. This hazard is particularly evident in Vietnam. At the majority of airfields, special security measures have been required to reduce aircraft damage from Viet Cong snipers on the field perimeters. These measures have been only partially successful in diminishing the threat. As recently as December 1964, an instance was reported of an A-1E aircraft being hit by ground fire on post-flight runup at Bien Hoa Airfield.[24]

Due to the nature of conflict in Vietnam, complete elimination of this hazard is a continuing problem not easily or completely solvable. A possible (but admittedly partial) solution is to increase night air operations and thereby use the natural cover and protection of darkness to avoid the snipers bullet.

The Aircraft Losses Operations Analysis Working Group, appointed by MACV early in 1964 to study methods of reducing aircraft damage and

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[23] *Ibid.*, MILREP Week of 11 Apr 64, p. 12.

[24] *Ibid.*, MILREP Week of 12 Dec 64, p. 6.

loss, arrived at several conclusions which support increased utilization of the hours of darkness for air operations. In discussing night air operations the Group concluded that:

> Although there have been some night air strikes flown in Vietnam, the number of these operations has not been such as to offer full comparison with daylight operations. . . . Based on the observations of pilots who had flown night strike missions and Forward Air Controllers who had conducted night missions, certain obvious advantages are pointed out:
>
> (a) Enemy camp fires and muzzle flashes are quite easy to locate at night.
> (b) Attacking aircraft are hidden from view more easily.
> (c) Enemy troops are presented with an ill defined target.
> (d) Harassment of the enemy at night will have a psychological effect and will deny troops the opportunity to rest.
>
> . . . .
>
> All pilots in the investigative committee were highly in favor of carrying out certain night operations and expressed a belief that attacks would prove even more effective than daylight attacks. /Underlining mine/
>
> . . . .
>
> Pilots who had operated in the northern or mountainous region were not as enthusiastic in their regard for night operations as those having experience in the Delta area. Both groups agreed that night operations could be increased and that training in night operations was needed.[25]

It is important to note that the people participating in this group recognized that insufficient large scale night air strike or airmobile operations had been conducted (to that date) to draw any valid comparisons with similar day operations or to arrive at final conclusions.[26] They did conclude, however, that "the hit rate on strike aircraft can be reduced through use of improved weapons, taking full advantage of the load carrying capability of all strike aircraft, simultaneous attack with three or more aircraft in each wave and increasing

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[25] Aircraft Losses Operations Analysis Working Group, "Minimizing Aircraft Damage and Losses from Enemy Ground Fire" (Saigon, Vietnam: U. S. Military Assistance Command, Vietnam, 30 Jul 64), p. 109.

[26] *Ibid.*, p. 110.

night strike operations."[27] [Underlining mine]

In commenting on development of more effective close air support operations in the II Corps Tactical Zone in Vietnam, the MAAG Senior Advisor stated that "an additional factor in use of air support is its utilization as a threat as well as a weapon. During good flying weather air support plays an important role in suppressing VC activity during daylight hours."[28] With development of an effective night attack and reconnaissance capability, there is no reason to believe that this suppressive role cannot be extended into a twenty-four hour operation. This should be one of our primary air objectives in Vietnam.

Whether the means employed are on the ground or in the air, the ultimate objective of a combatant is to find and pin-point a target for destruction by ground or air weapons. In Vietnam, a great deal of effort has been directed toward use of aircraft for widespread day and night visual reconnaissance. However, night, the exploitable ally, tends to favor the soldier on the ground and limit the capabilities of the "eye in the sky." Some early World War II experiences and difficulties with daytime offensive air operations over jungle terrain were reported by XIV Corps during the Bougainville operations. (These problems are further magnified in a night environment.)

> In operating over jungle terrain tactical air units required careful and thorough briefing. Even after such briefing pilots were sometimes unable to find the target area. This was due to no fault of the pilot but rather to the general absence of landmarks

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[27] Ibid.

[28] Office of the Director Advanced Research Projects Agency, Field Unit, Vietnam and Joint Operation Evaluation Group, Vietnam, "Evaluation of Test Results of the Employment of OV-1 (Mohawk) Aircraft in Support of Counterinsurgency Operations" (Saigon, Vietnam: Office of the Director Advanced Research Projects Agency, Field Unit, Vietnam and Joint Operation Evaluation Group, Vietnam, 19 Jul 63), Annex 9, p. 4.

> in jungle terrain and the total inability of the naked eye to spot any sign of jungle activity on the ground.[29]

As our airborne reconnaissance and interdiction effort increases during daytime, the enemy increases his movement and operations at night. "Heavy reliance on visual reconnaissance permits the enemy the freedom of movement in periods of low visibility and particularly at night."[30]

Although a modern sophisticated army has an ever-increasing capability in the field of reconnaissance, it is still largely dependent on visual acquisition of targets, particularly in a jungle warfare environment. "Finding the enemy is one of the main difficulties in military counter-insurgency operations."[31]

The deployment of OV-1 (Mohawk) aircraft to Vietnam in September 1962 was to test capability of this type of equipment "to provide continuous surveillance over a limited area and to conduct night operations as necessary."[32] Although results of this test were encouraging during daylight operations, night imposed restrictions which proved to be almost insurmountable. In his evaluation of test results of the Mohawk deployment, the Assistant Director of the Joint Operation Evaluation Group, Vietnam stated:

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[29] O. W. Griswold, Major General, U. S. Army, "Report on Lessons Learned in the 'Bougainville Operation'" (Bougainville, Solomon Islands: Headquarters XIV Corps, n.d.), p. 18.

[30] Office of the Director Advanced Research Projects Agency, Field Unit, Vietnam and Joint Operation Evaluation Group, Vietnam, "Evaluation of Test Results of the Employment of OV-1 (Mohawk) Aircraft in Support of Counterinsurgency Operations" (Saigon, Vietnam: Office of the Director Advanced Research Projects Agency, Field Unit, Vietnam and Joint Operation Evaluation Group, Vietnam, 19 Jul 63), Annex 2, p. 7.

[31] H. Speier _et al._, _op. cit._

[32] U. S. Army Concept Team in Vietnam, "Employment of OV-1 (Mohawk) Aircraft in Support of Counter-insurgency Operations," Final Test Report (Saigon, Vietnam: U. S. Army Concept Team in Vietnam, 25 May 63), Tab 1, p. 1.

> Visual reconnaissance plays a large part in the surveillance of the enemy. However, it plays this role by default. The VC conduct the major part of their movements in combat operations during the hours of darkness. The need for maintaining surveillance over this important phase of the enemy activities has long been recognized, but the state of the art has provided only a limited capability in this direction. . . . Since the VC move during the hours of darkness whenever possible, it is logical to assume that visual detection is feasible in the closing hours before a raid when daylight is useful for the final VC preparation or implementation phase. This means that provision should be made for covering the entire country.[33]

Maintaining visual observation of an entire country, the size of South Vietnam, is beyond the practical capabilities of present ground and air force available in that country. Such an operation during daylight hours would be difficult; and to expand visual surveillance missions on a significant and meaningful country-wide scale into the hours of darkness is seemingly impossible. Cover and concealment provided by darkness is as much the ally of the Viet Cong as neighboring "neutral" sanctuaries. As previously stated, the combination of natural cover and concealment afforded by a jungle battlefield and the additional concealment inherent in darkness present a formidable obstacle to observation of enemy activity. Several American advisors to ARVN units made specific comments on the Mohawk Project Test Report which further substantiates the problems of finding and fixing the Viet Cong. The Senior Advisor to the 7th Infantry Division (ARVN) claims that "difficulty in confirming VC unit locations can be attributed to 3 factors.

> a. Excellent use of camouflage and concealment by the VC.
> b. The continued movement of VC units within the Tactical Zone, normally during the hours of darkness and in small groups.

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[33]Office of the Director Advanced Research Projects Agency, Field Unit, Vietnam and Joint Operation Evaluation Group, Vietnam, op. cit., p. 5.

c. The time delay experienced between the original sighting, reporting to ARVN G-2 and the time the Mohawks received the mission.[34]

The G-2 advisor assigned to Advisory Team 51 observed that "the VC rarely move during daylight hours. When they do, they do not expose large elements to air observation."[35] In the open areas of the Delta region the problems were not appreciably diminished. The Army Concept Team In Vietnam (ACTIV) report on the use of Mohawks in the target acquisition role included the following statement:

> The VC operating in the Delta areas were well trained in the use of camouflage, cover, and concealment. They intermingled with the population, massed only when necessary, and as a rule moved during the hours of darkness. Mohawk crews seldom detected and identified large groups of insurgents.[36]
>
> On one night mission flown in the southern Delta area, attempts were made to conduct visual observation under the light of flares dropped by an O-1 aircraft. Results were marginal. Villages, canals, roads, and large groups of people were easily detected, but positive identification was not possible. . . . A further attempt to conduct visual reconnaissance of a canal using the landing light of the Mohawk provided little specific detail, and the aircraft was fired at several times. Defensive fires could not be returned because it was impossible to differentiate between friend and foe.[37]

The importance of night visual reconnaissance cannot be overemphasized, but it is also important to recognize that beneath the canopy of primary jungle, contrast between darkness of night and darkness of day becomes a contrast of black and dark gray rather than of black and white. Sophisticated detection devices developed for night reconnaissance should also be used, where feasible, during daytime to

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[34] U. S. Army Concept Team, Vietnam, _op. cit._, App. 3, Annex A, p. A-28.

[35] _Ibid._, App. 5, Annex A, p. A-43.

[36] _Ibid._, p. 35.

[37] _Ibid._, p. 36.

penetrate the everpresent darkness of the VC infested jungle. In rebutting the comment of the Assistant Director of JOEG-V ("The VC conduct the major part of their movements in combat operations during the hours of darkness."), the Senior Advisor to the ARVN I Corps had this to say:

> This statement is true of VC movements in combat operations within I TAC ZONE. However, the primary mission of I Corps is to interdict VC infiltration into RVN. VC infiltration movement does not take place during the hours of darkness. . . . Infiltration movement occurs between the morning meal, prepared at approximately 0600, and the evening meal, prepared at approximately 1930.[38]

It is considered safe to assume that with an increase in air action against infiltration routes, even the infiltrators will be forced to rely more heavily on use of the added protection and concealment of the nighttime jungle. The ally is always present with its intrinsic cover and concealment, exploitable by the willing.

We have discussed cover, concealment, secrecy, and surprise as elements inherent in night air and ground operations in Vietnam. The final factor, heat, is also characteristic of Vietnam and is manifested markedly in the level of activity of American advisors as well as the Vietnamese.

When first confronted with the seemingly apathetic attitude of the Vietnamese military man, American advisors were hard pressed to disguise their feelings of frustration and anger. Only time and continuous exposure to the sweatbox environment that is Vietnam tempered this feeling. One patrol with an ARVN unit through the central highlands jungle or one midafternoon combat mission in a VNAF fighter-bomber made believers of the severest critics. In the southern delta

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[38]Office of the Director Advanced Research Projects Agency, Field Unit, Vietnam and Joint Operation Evaluation Group, Vietnam, op. cit., Annex 5, p. 7.

regions of Vietnam, the steaming swamps and rice fields offer even less protection from the searing sunlight. The characteristically frail and normally mal-nourished Vietnamese soldier or airman is ill-equipped physically for sustained daytime military operations under these conditions. The more one ponders this situation the more difficult it becomes to reconcile continued emphasis on large scale day operations. In consideration of the factor of heat alone, how much more logical it would seem to be to commit ground forces in the relative coolness of the night. Examination of the problem of employment of ground forces at night is beyond the scope of this thesis, but it is a problem in Vietnam that warrants further serious study.

Night warfare in Vietnam is no different than such warfare in any other country of the world, but it must be fought offensively by friendly forces as well as the enemy if we are to achieve victory. The gradual trend in this direction for both ground and air forces is the evolving doctrine to which this paper is addressed.

CHAPTER III

NIGHT AIR OPERATIONS IN VIETNAM

To provide a logical but diversified approach to the history of night air operations in Vietnam, each of the years, 1962, 1963, and 1964 will be examined, in order, from three distinctive viewpoints. The year 1962 will be analyzed primarily from a standpoint of personal experiences; 1963, through questionnaire and interview derived recollections of other participants and combatants; and 1964, through an analysis of the lengthy and detailed MACV MILREPS. The central theme of night air operations in Vietnam will be woven throughout the discussion by reference to numerous other official records which document the slow but steady increase in emphasis on air operations at night in that embattled country.

Personal Experiences, 1962

A few key facts, events, dates, and statistics will help to establish a framework for the discussion.

> The mission of the Vietnamese Air Force is to support the Army, including troop transport, air-ground support, liaison, reconnaissance and aerial supply and evacuation. Functionally it is a segment of the Vietnamese Army and completely subordinate to the Army General Staff. The Deputy Chief of Staff (Air) of the Army General Staff, is in effect, the Commander of the Vietnamese Air Force.[1]

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[1] STRAC Country Study, "South Vietnam," Prepared by Assistant Chief of Staff G-2, STRAC Intelligence Center (Fort Hood, Texas: Headquarters, III Corps and Fort Hood, 26 Jun 64), p. 99.

The Vietnamese Air Force in [redacted] around a limited number of C-47 transports, two squadrons of L-19 (O-1A) liaison and visual reconnaissance aircraft, one squadron of T-28 training planes converted to a fighter-bomber role, a few H-34 helicopters, and one squadron (25 aircraft) of AD-6 (A-1H) fighter-bombers. There have been no significant changes in types of aircraft operated by the Vietnamese to this date (March 1965), and "since the terms of the Geneva Accord severely limit the introduction of new equipment, particularly jet aircraft, no major change in the Vietnamese Air Force is expected for several years.[2]

Changes which did take place in the VNAF during late 1961, 1962, and subsequent years, came about due to introduction of U. S. Army, U. S. Air Force, U. S. Navy, and U. S. Marine aircraft into the country, accompanied by an ever increasing number of American advisors.

The first United States Air Force element to deploy to Vietnam was a detachment of the 1st Air Commando Wing. This detachment, known as Project FARMGATE, arrived at Bien Hoa Airfield on 5 November 1961 and was placed under operational control of the 2d Air Division.[3] The first United States Army air support elements to arrive in Vietnam were the 8th and 57th Transportation Companies (Light Helicopter). The date was 11 December 1961.[4] These units were the first major United

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[2] *Ibid.*, p. 100.

[3] U. S. Air Force, "Fact Sheet on Special Air Warfare," (Washington, D. C.: Office of Information, Office of the Secretary of the Air Force, Internal Information Division, Mar 65), p. 14.

[4] Director of Army Aviation, "U. S. Army Aviation Operations in South Vietnam," Office of the Deputy Chief of Staff for Military Operations, Department of the Army (Washington, D. C.: Department of the Army, 1 Oct 62), p. 9.

States contribution to the Republic of Vietnam air effort and heralded the beginning of a massive air power buildup which numbered 923 assigned aircraft as of 2 January 1965.[5] (See Table 1 for a detailed listing of aircraft, by type, employed in Vietnam as of 2 January 1965.)

During 1962, however, the overall air effort was characterized by improvement in operations and sortie rates more than by an increase in numbers of aircraft introduced into the country. The feeling prevailed that American ingenuity and management practices alone would be adequate to deal with the situation; and results <u>were</u> impressive. From a 1961 average of 120 VNAF sorties per month, the sortie rate increased in the last quarter of 1962 to 718 sorties per month. The joint VNAF/USAF sortie rate increased from a low of 225 in February to a high of 1095 in November.[6] VNAF/USAF sorties of all types totaled 8055 during 1962.

A detailed breakdown of these sorties, by type, was apparently never attempted on a countrywide basis although each ASOC submitted daily Operations Activities Reports (OPSACTS) and Intelligence Summaries (INTSUMS).[7] The only record found which did give some indication of

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[5]U. S. Military Assistance Command, Vietnam, "Military Reports," Published Weekly, 11 Mar 64 through 31 Jan 65 (Saigon, Vietnam: U. S. Military Assistance Command, Vietnam, Week of 26 Dec 64), pp. 6-7. (The figure 923 does not include the 48 USAF jet powered aircraft actually available in Vietnam but not listed as assigned there.)

[6]Office of the Director Advanced Research Projects Agency, Field Unit, Vietnam and Joint Operation Evaluation Group, Vietnam, "Evaluation of Test Results of the Employment of OV-1 (Mohawk) Aircraft in Support of Counterinsurgency Operations" (Saigon, Vietnam: Office of the Director Advanced Research Projects Agency, Field Unit, Vietnam and Joint Operation Evaluation Group, Vietnam, 19 Jul 63), p. 11-b.

[7]These were detailed reports listing each sortie by mission type and were summarized weekly by Second Air Division. All commands or agencies which might have kept these 1962 summaries, including, Second Air Division, 13th Air Force, PACAF, and ACSI, were quiried for information on [redacted]cords, but to no avail.

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TABLE 1

AIRCRAFT STATUS IN VIETNAM, 2 JANUARY 1965

Force of Assignment	Type Aircraft	Number of Aircraft Assigned	Number of Aircraft Available
USAF	O-1F	23	18
"	U-10B	3	2
"	C-123	72	59
"	C-47	7	6
"	C-54	4	4
"	A-1E	48	41
"	B-57	0	13
"	RB-57	0	3
"	RF-101	0	11
"	U-3B	2	2
"	F-100	0	13
"	F-102	0	10
"	HU-16	0	2
"	HH-43F	0	6
Sub-total		159	190
VNAF	A-1H	91	78
"	T-28B	4	4
"	O-1A	38	31
"	C-47D	31	25
"	RC-47D	3	3
"	UH-19	16	16
"	RT-28	5	5
"	EC-47D	1	1
"	U-17A	25	25
"	U-6A	8	8
"	H-34	60	58
Sub-total		282	254
USA	UH-1B	278	238
"	CV-2B	33	26
"	JOV-1	12	12
"	O-1F	50	46
"	U-1A	27	20
"	CH-37	9	5
"	U-6	31	N/A
"	U-8	11	8
Sub-total		451	355
USMC	UH-34D	27	23
"	O-1B	3	3
"	C-117	1	1
Sub-total		31	27
GRAND TOTAL		[redacted]	826

[redacted] **UNCLASSIFIED**

the <u>type</u> of flying activity during 1962 was a 2d Air Division study generated by the ever present and continuing controversy over Air Force reaction to Army requests for immediate air support. The author contributed the sortie records of II ASOC for the period July-October 1962, and the resulting study revealed a relatively low percentage (1.6 per cent) of sorties flown in response to immediate air requests.[8] This figure is indicative of the general tenor of the air effort in Vietnam during 1962. The main effort of VNAF and USAF pilots was directed toward training and general improvement of combat proficiency, and the average ground forces engagement with the VC was of such a nature and duration that close air support (as it was provided at that time) proved to be of little direct value to ARVN forces in the field. The majority of VNAF/USAF air operations consisted of interdiction, reconnaissance, and supply airlift, while the U. S. Army and U. S. Marines' air effort was concentrated on heliborne and liaison operations (personnel lift and resupply).

As for night air operations during 1962, the author's recollection centers around several significant events or circumstances. The first of these occurred within ten days after arrival in Pleiku. A U. S. Army sergeant, in a moment of possible apprehension over his assignment to Vietnam, slit his throat. Immediate evacuation to a hospital was necessary and was accomplished by a skillful and daring C-123 aircrew who flew, without benefit of navigational aids, from Saigon on a pitch black night and landed their aircraft on the short, rolling, rusty PSP runway at Pleiku, aided only by the lights of jeeps

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[8]Office of the Director Advanced Research Projects Agency, Field Unit, Vietnam and Joint Operation Evaluation Group, Vietnam, <u>op. cit.</u>, p. 6.

parked at either end of the airfield. The operation was a success, the sergeant survived, and the U. S. Air Force made its entry into night air operations in Vietnam. This type of flying, although under somewhat less severe conditions, became almost routine during the ensuing months, and many American and Vietnamese soldiers and airmen owed their lives to the C-123 pilots and their "high-tailed" ambulances.

The second event resulted in far reaching effects. The Vietnamese radar site at Pleiku (call-sign PAGODA) was declared operational during the final week of March 1962. Manned by one American and several Vietnamese trainee controllers, it functioned primarily as a traffic control and flight-following facility assisting Air Force and Army aircraft in navigating from point to point within the central part of South Vietnam. It was this radar site, equipped with World War II TPS-1 (search) and TPS-1D (height) radars, that first detected what was thought to be clandestine enemy night air operations originating in Cambodia and entering Vietnamese airspace. Exact dates cannot be recalled, but approximately 16 or 17 April 1962, radar contacts with unidentified airborne targets were made beginning about midnight and continuing for several hours. In consideration of the "newness" of this "old" radar and the fact that trainee controllers had made the first identification, activity the first night was limited to attempts by hastily assembled U. S. Air Force and VNAF officers to determine what the radar plots actually were. The only experienced controller concluded that something <u>was</u> on the scopes and it <u>was</u> definitely airborne, although moving very slowly (estimated eighty to one-hundred miles per hour). Because there were no provisions for countering an enemy airborne threat at that time, we could only watch the "blips" as they

slowly moved north along the Cambodian border and eventually faded. The next night was a different story. Vietnamese manned T-28 fighter-bombers had arrived at Pleiku that afternoon. The Vietnamese Director of the JOC and numerous other American and Vietnamese observers from Saigon had also arrived. A "Scramble" communications line had miraculously been installed from the radar site to the flightline in less than twenty-four hours and the T-28 pilots were standing by at the airfield to take-off on a moments notice: and take-off they did. At about one o'clock in the morning, "blips" reappeared on the scope and the first air defense mission of this little counterinsurgency was was launched into the moonlit night. Nothing was sighted, but the enthusiasm of the chase was something to see and hear. Moonlight proved to be the eventual key to identification of the targets, but not before an element of U. S. Air Force F-102 interceptors from the Philippines had conducted a lengthy test (Project WATERGLASS) to determine their capabilities to shoot down low, slow-flying targets. Four U. S. Navy AD-5 (A-1E) radar equipped aircraft also flew a large number of fruitless missions chasing the illusive targets around the night sky. The final answer to the puzzle was determined almost a year later (in February 1963) when a sharp-eyed AD-5 pilot visually identified the suspected airborne menace as flocks of birds. Consultation with Audubon experts in the area (something which had not been considered previously) confirmed the fact that moonlight migration is one of the habits of geese in this part of the world, and that this migration does take place in February, March, and April on nights when the moon if full. The only consolation in the whole fiasco was the proof that Pleiku radar site, with its old equipment, was performing far above expectations; more important and more pertinent, this incident marked the beginning of

night air operations by fighter aircraft in Vietnam.

An interesting side-light to this event was discovery by night fliers of the extent to which the Plateau jungle was being burned. U. S. Army helicopters had taken off the second night of the radar sightings in an attempt to determine whether clandestine aircraft were air dropping supplies. The helicopter pilots reported, and the author later confirmed personally, the fact that literally hundreds of large jungle fires were burning over the entire Plateau area. There was some speculation that the radar "blips" detected were ghost targets anomalously propogated by a temperature inversion induced by rising heat from the jungle fires. However, this theory was never confirmed. During the early spring months of February, March, April, and May, the Plateau jungle has dried to the extent that it can be burned by the Montagnards (natives of the Plateau) to make room for planting small crops of rice and tobacco. During these months, the sky is hazy with smoke during the day, and the night sky is lighted as if from the lights of a large city. This is a seasonal factor which makes night identification of ground targets difficult in I and II Corps Tactical Zones, particularly when pilots are attempting to locate the VC by light from their campfires. This is a characteristic of the central and northern parts of South Vietnam which we may assume will not change significantly in the years to come.

The only other specific event of a personal nature which relates to night air activity during 1962 was cited in the introductory chapter to this thesis. However, several important steps were taken during this year which directly or indirectly affected the future of night air operations and which are worthy of mention. The first of these was development of the "flaming arrow [redacted]

Early in 1962, personnel of the Field Command Advisory Detachment, Vietnam, recognized that the new "strategic hamlet" program would never be successful unless some method could be developed to assist aircraft in providing air support to hamlets and outposts under night attack. Although at that time there was limited capability to perform air support missions at night, MAAG and 2d Air Division planners went ahead with development of a nationwide project to place pivotable bamboo and canvass constructed "arrows," outlined with gasoline filled cans, in each village and outpost. Air officers from 2d Air Division developed dimensions of the device and MAAG catalogued exact GEOREF positions and configuration of each facility at which "arrows" were to be installed. The "arrows" could be ignited in a few seconds and turned to point in the direction of the main VC attack. In addition, each outpost was to lay whitewashed rocks around the post primeter which would show up plainly in daylight or under the glare of air-dropped flares. The plan received the blessings of the ARVN Field Command in February and was first tested at an abandoned outpost twenty kilometers south of Saigon. ARVN troops built the "arrow" and 2d Air Division, MAAG, and the ARVN combined forces to conduct two flight tests late in February. One test was conducted during daylight, and no difficulty was experienced in identifying the post. The second flight test was conducted at night by a C-47 flare aircraft which was vectored to the general vicinity of the outpost by the TACS radar at Tan Son Nhut, and again the pilot easily identified the post. The ARVN Field Command was favorably impressed by results of the tests and in March 1962 ordered "arrows" installed at every remote military and paramilitary facility in Vietnam. The plan caught on quickly. First Corps was the

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first command to install "arrows" followed by II Corps and III Corps. The "Flaming arrow" was first used in July, under actual night attack conditions, by a Special Forces "A" Team in the southern part of II Corps Tactical Zone. The attack was beaten back supported by a C-47 flareship and several VNAF AD-6 (A-1H) fighter-bombers. The plan had proved its value. Since that time, the "flaming arrow" has been used to advantage by hundreds of outposts and villages and has become a permanent fixture on the Vietnamese scene. The value of the "arrow" went beyond its simple value as an identification device. Lt Col. Bernard Big, Inf., USA, Senior Advisor to the Self Defense Corps (SDC) and Civil Guard (CG) stated that morale of the outposts was greatly improved by setting up the "arrows."[9]

Aside from the increased night alert posture maintained by aircraft at Tan Son Nhut and Bien Hoa (primarily an air defense alert), and an occasional scramble to go "bird-hunting" or flare-dropping, the night air during the early summer months of 1962 was left to migrating geese and infrequent medical evacuation missions by C-123 and helicopter aircraft. The relative absence of night air activity at Pleiku airfield during this period was pointedly demonstrated one bright morning when upon arrival at the flightline to brief an early strike mission the author discovered literally hundreds of bamboo stakes firmly planted in the PSP runway. Viet Cong Propoganda leaflets were affixed to the pole tops; a demonstration of the questionable capabilities and/or alertness of the ARVN troops who were supposedly guarding the runway perimeter.

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[9]Interview with Maj. William S. Schroeder, Inf., USA, USACGSC Student, 11 Feb 65. (Major Schroeder was instrumental in establishing the "flaming arrow" procedures and cataloging all villages and outposts which constructed the "arro[redacted]

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As stated previously, the summer months of 1962 saw the beginning of an earnest but at times woefully inadequate attempt to provide air support to villages and outposts at night. By mid-fall, C-47 flareships were becoming a familiar sight in the night sky over Vietnam. However, their use was more or less limited to an area in the immediate vicinity of Saigon (in what was then the III Corps Tactical Zone). This area, being more heavily populated, also experienced a greater number of night attacks and outpost harassments. During the period from September through December 1962 there were only two short periods during which a C-47 flareship was actually located in II Corps area. Both of these deployments resulted from rumors of planned VC attacks on important ARVN installations in the area; attacks which never materialized. Attacks did continue at night but always at some remote village or hamlet where radio equipment was not available and the villagers could not immediately contact aid.

One additional event in 1962 gave some indication of an evolving interest in utilizing aircraft at night. The 23rd Special Warfare Detachment (SWAD) arrived at Nha Trang in September with six JOV-1 (Mohawk) aircraft. Although their mission was never directed specifically toward operations at night, this unit did have a night capability and some effort was made to use this potential. During the final two months of 1962, the 23rd SWAD exercised its limited flare illumination capability (the Mohawk carries six flares which can provide a total of eighteen minutes of illumination) by flying two sorties in support of two separate railroad trains under night attack. Among other missions, "during the period 1 November 1962 - 28 February 1963, the 23rd SWAD provided the following air support to the II Zone, MRSS [Military Railway Security Service] . . .

Special flare missions based on analysis of previous VC actions in an effort to trap the VC and/or prevent damage as a result of VC sabotage during the hours of darkenss."[10] This unit also maintained a night alert status similar to that which USAF/VNAF maintained at Bien Hoa and Tan Son Nhut. "At night a standby aircraft equipped with flares and a standby crew were designated to enable 'Scramble' illumination missions to be launched within 15 minutes of receipt of the mission request."[11] An indication of utilization of these aircraft for illumination missions can be determined by noting that during the period 16 October 1962 to 15 March 1963 the 23rd SWAD flew 778 combat support missions. Only fourteen of these were night illumination missions.[12]

The Mohawk has an excellent night capability, but this fact was not fully recognized by ARVN commanders, or by their advisors, during this period of time. The final test report of the 23rd SWAD deployment mentioned that "Mohawk equipment includes an AN/ARA-31, which permits the pilot to home on any tactical FM radio. This capability was used for locating friendly units and for finding target areas for night flare drops."[13] However, the test report did not indicate exactly how often this capability was used or, in fact, if it was used.

Personal experiences and memories form an unsubstantial base for development of a history, especially when recorded at a time relatively far removed from the actual events. However, for the purposes of this

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[10] U. S. Army Concept Team in Vietnam, "Employment of OV-1 (Mohawk) Aircraft in Support of Counter-Insurgency Operations," Final Test Report (Saigon, Vietnam: U. S. Army Concept Team in Vietnam, 25 May 63), Tab A-5, p. 2.

[11] Ibid., Tab 5, p. 2.

[12] Ibid., Tab 1, p. 4.

[13] Ibid., Tab 3, p. 3

thesis, memories of the author and other individuals directly involved with making that history do point to an awakening interest in night air operations which was evident during this first year of substantial American participation in counterinsurgency operations in Vietnam.

The Advisors' Point of View, 1963

The author prepared a questionnaire on the subject of night air operations in Vietnam and distributed it to sixty-six members of the regular 1964-65 class of the U. S. Army Command and General Staff College who had recently returned from duty in South Vietnam. Forty-one of these questionnaires were completed. Twenty-four of these officers were on advisory assignments in Vietnam which resulted in personal experience with night air operations. An analysis of their comments will serve as a foundation for discussion of night air operations in Vietnam, 1963.

To establish the 1963 experience factor for officers who completed questionnaires, see Graph 1. This graph will also serve to fix the time frame from which specific comments by specific officers are taken. A complete listing of those officers whose experiences are recounted is contained in the bibliography.

It will be noted that all but two of the individuals were in Vietnam during part of 1963. Although they don't bear directly on 1963 air operations, the following comments of Majors Pulsipher, McLean and Captain McKee are of particular interest due to the relative scarcity of information on night air activity during 1961 and 1962. Major Pulsipher was assigned to a Special Forces "A" Detachment at Camp Hoa Cam, fifteen kilometers west of DaNang in I Corps area. He particpated in eighteen night ground operations and felt that air support could have

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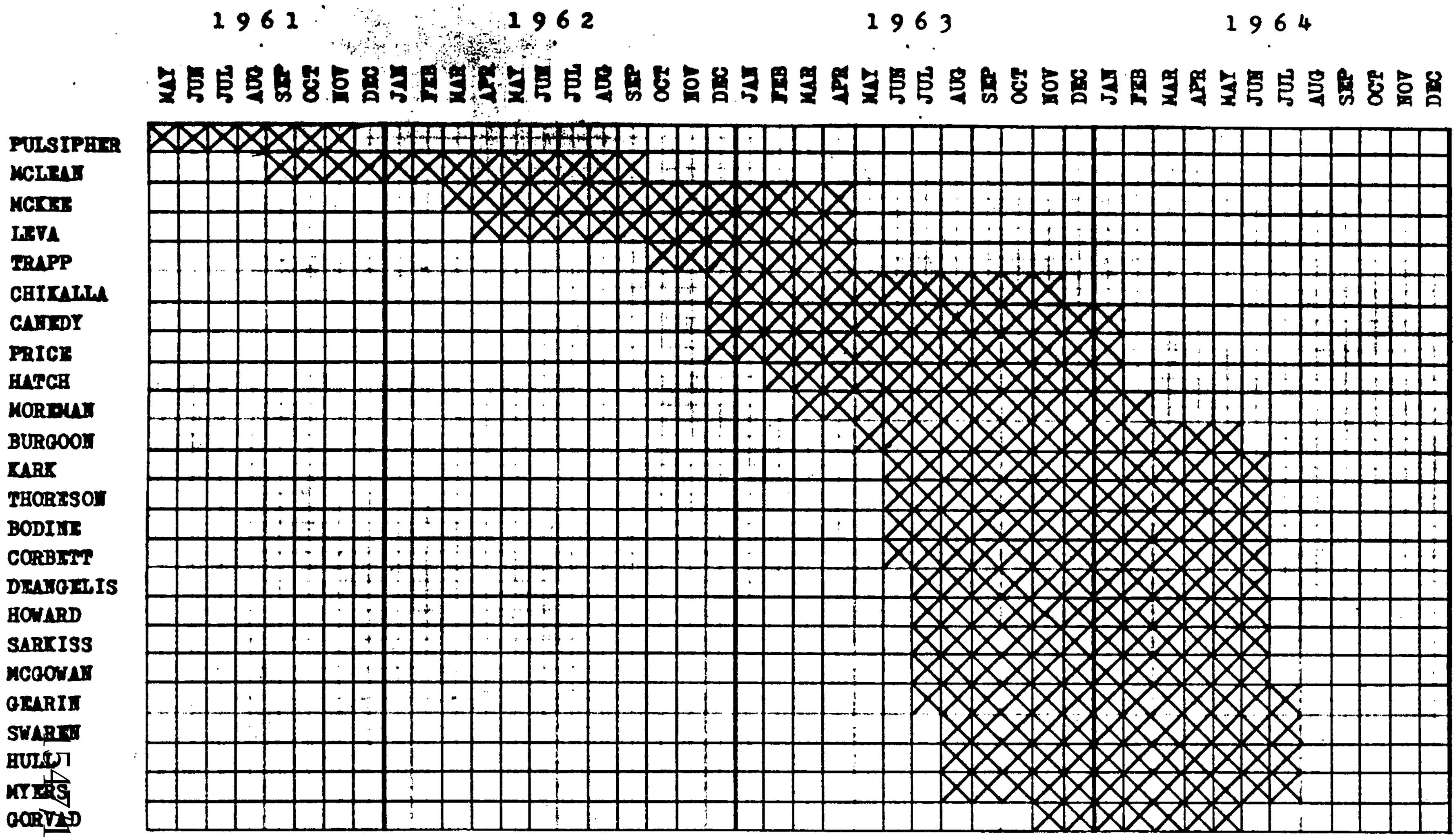
GRAPH 1

VIETNAM TOUR LENGTHS AND TIME PERIODS OF OFFICERS
SUBMITTING COMPLETED QUESTIONNAIRES



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[redacted]

been used to advantage on eight of these. He indicated, however, that at that time, there was no responsive source of night air support.

> Air Force and Army helicopters refused to fly at night except for parachute operations. . . . No air [was requested], it was too slow, [we] used artillery flares about 10 times on night contacts also 60mm mortar flares and hand flares. . . . We could not depend on close air support so quit asking and used artillery fires when possible--if out of range we just used what we had.[14]

Major McLean was also stationed in I Corps area as an armored regiment advisor. He participated in only one night ground operation during his tour and commented on the extreme lack of air support during this period as follows:

> The unit I advised was fragmented over the entire I Corps area--as a result no operations involving the whole unit were undertaken--the one operation mentioned used only one company in support of a 3d Inf Rgt operation. At the time there were no U. S. channels for request of close air support. Vietnamese channels for air support north of DaNang took so long that commanders did not even consider such requests.[15]

Captain McKee was stationed in Tay Ninh Sector approximately eighty-five kilometers northwest of Saigon in II Corps Tactical Zone. He participated in "twenty to thirty" ground operations at night but all of these were with small foot patrols. He felt that night flare or close air support could not have been used to advantage during this type of operation because it "would have normally exposed us rather than VC." He observed the use of airborne flares in defense of villages under attack "at least 30 times," and felt that this was the only type of night engagement in which close air or flare support might be used effectively (although he recognized several additional capabilities).

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[14]Questionnaire, Maj. Elwin D. Pulsipher, Inf., USA, USACGSC Student, 19 Nov 64.

[15]Questionnaire, Maj. R. P. McLean, Armor, USA, USACGSC Student, 19 Nov 64.

> During my tour flares and night close air support were available primarily for relief of posts under attack. [Night close air/flare support] would be excellent for harassment or interdiction on a daily basis.

An interesting comment which demonstrates the increase in night air capability during the latter part of 1962 was Captain McKee's statement that response time for requests for air support was "faster at night."[16]

These few comments are important to show the rapid increase in emphasis and use of aircraft at night during late 1962 and lead us into the general analysis of comments and statistics derived from the larger number of officers who served in Vietnam during a significant number of months in 1963.

The questionnaire attempted first to establish the amount of night offensive ground activity conducted during 1963 and then to compare this activity with related night air operations. Of the 21 officers questioned, 16 had participated in a total of 385 night offensive ground operations. (The five non-participants were aviation, artillery, or headquarters advisors.) It was generally concluded that night air support could have been used to advantage on 136 of these operations (35 per cent). Illumination and/or close air support was actually requested on 62 (16 per cent) but provided on only 27 (7 per cent) of these actions.

The multiple and complex reasons for failure to fly requested night air support missions are buried, perhaps forever, in every level of the time consuming chain of command through which air support requests had to pass in Vietnam before aircraft actually became airborne.

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[16] Questionnaire, Capt. R. W. McKee, Armor, USA, USACGSC Student, 19 Nov 64.

[redacted]

One aspect of the proble[redacted] a lack of knowledge of available air support and how to go about getting it in time to do some good. Only seven of the sixteen officers who had gone into the field at night had been briefed on overall air support available to them. Only eight were advised by higher headquarters directly when airborne or strip alert aircraft were going to be in the area of their operation and available on call for their use.

The length of time involved in a contact with VC forces at night was reported as varying between three to four minutes and five to six hours, depending on size of forces involved and circumstances under which contact was made. The average size VC force engaged at night was estimated to be of platoon size although contacts with forces from 5 men to 500 men were also quite common. Major McGowan, a Civil Guard battalion advisor, stated that although he considered his night operations conducive to the use of air support, the time of engagement was usually too short to obtain such support.

> [Time] is the most important limiting factor; behind this is the slowness of processing through VN channels a request for immediate air support; and third, lack of ground/air communications limits effectiveness. . . . Aircraft must be in the air, available within 30 minutes of request. Direct ground/air communications must be available.[17]

There was widely varying opinion expressed by the officers questioned when asked to state an overall estimate of the effectiveness of air support in determining a successful operational outcome during night operations in South Vietnam.

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[17]Questionnaire, Maj. Robert S. McGowan, Armor, USA, USACGSC Student, 19 Nov 64.

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Major Trapp, a Special Forces "A" Detachment Commander, felt that night air support was "totally unsatisfactory."[18]

Captain Chikalla, assigned to the Vietnamese Ranger Command, claimed that night air support "was very effective when adequate communications were established."[19]

Major Price, an advisor to an infantry regiment, said that "air was an effective and valuable asset. The difficulty was in establishing priorities and overall coordination."[20]

Major Moreman, an advisor to the Chi Lang Training Center made the following comments:

> In a defensive situation the flares are very effective. In offensive situations there are many 'ifs' --area, location of enemy in relation to attacking forces (surrounded, etc.), numbers of enemy and ground forces leadership. But well coordinated air could have been effective several times on known enemy companies and battalions that were moving and crossing open areas at night or on known enemy night concentrations.[21]

Captain Burgoon, an artillery advisor, stated that night air support "wasn't effective unless we had a ship up in the area on an alert status."[22]

Major Thoreson, a ranger battalion advisor, felt that adequate and timely night air support could have been utilized in only 10 per cent of the night operations in which he participated.

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[18]Questionnaire, Maj. L. R. Trapp, Inf., USA, USACGSC Student, 19 Nov 64.

[19]Questionnaire, Capt. Gerald G. Chikalla, Inf., USA, USACGSC Studnet, 19 Nov 64.

[20]Questionnaire, Maj. George B. Price, Inf., USA, USACGSC Student, 19 Nov 64.

[21]Questionnaire, Maj. Marcus D. Moreman, Inf., USA, USACGSC Student, 19 Nov 64.

[22]Questionnaire, Capt. Kenneth L. Burgoon, Arty., USA, USACGSC Student, 19 Nov 64.

This figure is low since [redacted] area was almost entirely jungle (Zone D) where daylight observation was often limited to 5 meters. On the jungle periphery this percentage increases.

Major Thoreson also emphasized necessity for continued and widening use of a combination flareship/strike capability.

> During Jun-Dec '63 VC night attacks of hamlets, the VC would withdraw when flare support was provided. During Jan-May '64 VC would not withdraw unless air strikes were made along with flare support.[23]

Major Bodine, a 5th Infantry Division (ARVN) advisor, supported the previous statement when he observed that:

> Flareships were quite successful in breaking off attacks on hamlets. Close air support of units [was] not too successful due to difficulty in locating targets and marking friendly troops.

However, Major Bodine did state that night close air/flare support could have been used to advantage "in all cases where significant contact was made with Viet Cong."[24]

Major Corbett, an artillery and Sector advisor in Pleiku Province, strongly supported use of flareships, particularly in the mountainous terrain of central Vietnam.

> Flare support is vital to operations in Vietnam. When under attack, illumination would immediately become the balance of power and force the VC to halt their assault. There have been several occasions where illumination alone has caused the VC to break-off.[25]

Major DeAngelis, an armored cavalry squadron advisor, indicated some of the limitations in use of night air support. He felt that night air support could have been used effectively on only 15 per cent of the operations in which he participated.

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[23] Questionnaire, Maj. David P. Thoreson, Inf., USA, USACGSC Student, 19 Nov 64.

[24] Questionnaire, Maj. James F. Bodine, Arty., USA, USACGSC Student, 19 Nov 64.

[25] Questionnaire, Maj. W. T. Corbett, Arty., USA, USACGSC Student, 19 Nov 64.

> Flares would be good if responsive to the ground commander since the VC move during the night in groups. Close air would not work where I was. [It was] difficult to control.[26]

Captain Sarkiss, a ranger battalion advisor in III Corps area, was also concerned with the communications problem:

> I feel they [night close air and flare support] are damn important. The biggest problem is communications. The ground element can't talk with the pilot of the aircraft.

Captain Sarkiss also observed that in the night operations in which he was involved, close air/flare support was not effective because engagements lasted such a short period of time, "but if a hamlet was being hit they could be of great assistance." He felt that night air support could have been used to advantage in approximately 50 per cent of the night operations in which he participated.[27]

Major Gearin, an infantry regimental advisor, concurred in this opinion:

> The defense of posts and towns were unquestionably conducive to the use of close air support; many night offensive operations could have been.

Major Gearin continued to say: "Until GVN can provide effective night close air support, a successful counter Phase II insurgency is impossible."[28]

Majors Swaren, Hull, and Myers, all of whom were infantry division advisors, were of the opinion that flare support was good but

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[26] Questionnaire, Maj. Joseph A. DeAngelis, Armor, USA, USACGSC Student, 19 Nov 64.

[27] Questionnaire, Capt. C. D. Sarkiss, Inf., USA, USACGSC Student, 19 Nov 64.

[28] Questionnaire, Maj. C. J. Gearin, Jr., Inf., USA, USACGSC Student, 19 Nov 64.

that night close air support was of doubtful value. Major Hull's comments summarized the mutual position as follows:

> The flare ships were extremely effective particularly in causing the VC to break off an attack against a post or watchtower. I have doubts about the effectiveness of close air fires at night. They weren't properly controlled.[29]

This lengthy but pertinent recording of the opinions of on-the-spot observers can be summarized by saying that, in general, 1963 saw the beginning of a widespread increase in use of and emphasis on night air operations in Vietnam, particularly in the area of illumination. During this period of time, ground and air forces became fully aware of the potential for operations at night under protective cover of air-dropped flares and airborne supporting fires.

Several additional events and statistics can be cited to round out the 1963 history of night air operations in Vietnam.

In an article based on 2d Air Division Operational Summaries and published in Air University Review, several key operations were discussed by the PACAF Intelligence Branch which document increased use and effectiveness of night air support during 1963.

> On various occasions the flare strike teams have conducted a running battle with the Viet Cong following break-off of the outpost attack. One instance of note occurred on the night of 20 June 1963 when a large force of regular Viet Cong was driven back by A-1H night air strikes from their attack on an outpost 25 miles east of Soc Trang in the delta area. The Viet Cong retreated in two groups, one by land and the other by sampan. With paraflares lighting the retreat routes, elements of tactical fighters pressed the fleeing enemy throughout the night.[30]

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[29]Questionnaire, Capt. Robert L. Hull, Inf., USA, USACGSC Student, 19 Nov 64.

[30]Lt. Col. James F. Sunderman, "Air Operations in Viet Nam," Air University Review, XV No. 6 (Maxwell Air Force Base, Alabama: Aerospace Studies Institute, Sep-Oct 64), p. 86.

Several other operations were noted in which weather played a dominant role.

On the night of 22 July 1963, for example, the Viet Cong struck an outpost situated on the bank of a river about 15 miles northwest of Bien Hoa. Rain showers were drenching the countryside from a 200- to 500-foot broken ceiling when a pair of VNAF T-28's was scrambled at Bien Hoa Air Base to aid the outpost.

Operating under a low ceiling in the rain, they spotted the Viet Cong in a wooded area near the fort. With minimum paraflare visibility, the T-28's made four bomb runs on the insurgent force. During these strikes they noted another enemy force attempting to overrun the fortress from the river side and diverted the attack, making repeated rocket and strafing runs on this group of Viet Cong.

Advised by the USAF C-47 flareship that the enemy had broken off the attack, the T-28's returned to their base. The pilots reported an estimated 40 Viet Cong killed. Several days later the official ground-confirmed reports indicated 68 dead Viet Cong.

One week later, at 2100 hours on 29 July 1963, a strong Viet Cong contingent struck another outpost 17 miles north of Bien Hoa. Responding to the outpost call for help, a B-26 light bomber took off in a heavy rain. Breaking out of the overcast at 3000 feet altitude, the pilot called for and got a radar vector to the general outpost area. Descending through the overcast, he broke out at 600 feet above the heavily wooded, hilly area. Darkness and rain enveloped the countryside, effectively hiding the outpost. The crew undertook a widening circular search for the fort and within ten minutes spotted it about six nautical miles north of the radar plot. The pilot immediately called radar control for a flareship vector through the overcast to the site, and within minutes the C-47 appeared. By the light of paraflares and directed by a flaming arrow signal from inside the fortress, the bomber crew worked over the insurgent force with seven low-angle strafing and rocket passes. Heavy enemy small-arms fire was encountered on each pass. Since the low ceiling and extremely poor visibility made conventional bombing attack procedures impossible, the crew improvised a strike plan. Lining up the target area on the fort lights, they made a treetop approach on each bomb run, pulling up into the overcast and pickling off their bombs at 1000 feet--lobbing them into the enemy ranks. . . . The Viet Cong broke off the attack and fled. The outpost was saved, and the paraflare/attack team returned to its base.[31]

The 23rd SWAD was also active in night operations during 1963. From a rather inauspicious beginning during the 16 March to 31 July 1963

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[31] _Ibid._, pp. 88-89.

period, during which only 3 night illumination missions were flown out of a total of 1,158 sorties,[32] the detachment began to emphasize night surveillance operations which had a definite deterrent value in control of VC activities at night.

> On the night of 24 Oct 63, during a night observation mission, a Mohawk observed a "red star cluster" over Binh Duong, Sector XT885970. The aircraft was over the outpost under attack in 3 minutes. Automatic weapons fire was observed at 5 different points. As the aircraft orbited the area the Viet Cong withdrew. The aircraft remained in the area for 45 minutes without further incident.[33]
>
> At 251955 Oct. (1963) during a night observation mission, the Mohawks observed a heavy volume of fire at Ben Cat, Binh Duong Province vicinity of XT731333. Immediate report was made to division TOC by Mohawk, artillery fired illumination and the Viet Cong withdrew.[34]

The importance of illumination in reconnaissance missions was emphasized. "Mohawk pilots have expressed the opinion that in remote areas on dark nights, reconnaissance of specific targets without artificial illumination is unsatisfactory."[35]

One final night air activity which developed late in 1963, and which is not documented in any other source, was the fropping of flares by U. S. Army TO-1D aircraft in support of hamlets under night attack. Major Kark, who commanded the 73d Aviation Company (Airplane surveillance) (Light), indicated in his questionnaire that during the final

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[32] U. S. Army Concept Team in Vietnam, "Supplement to Final Test Report, Employment of OV-1 (Mohawk) Aircraft in Support of Counterinsurgency Operations" (Saigon, Vietnam: U. S. Army Concept Team in Vietnam, 9 Sep 63), p. 2.

[33] U. S. Army Concept Team, Vietnam, "Mohawk Aircraft in the Target Acquisition Role" (Saigon, Vietnam: U. S. Army Concept Team, Vietnam, 1 Feb 64), p. 24.

[34] Ibid., App 1, Annex A, p. A-7.

[35] Ibid., p. 37.

months of 1963, aircraft of his command, assigned to the various division headquarters throughout the country, were often called upon to drop flares when the C-47 or C-123 flareships from Bien Hoa and Tan Son Nhut were committed in other areas and his aircraft were the only available source of illumination. Because these missions were flown strictly on a local basis to satisfy the requirements of a specific division commander, no official record was kept of the operations. However, Major Kark commented that over fifty flares per aircraft were dropped during the last two months of 1963 and the first five months of 1964.[36]

The year 1963 marked the first significant steps toward development of an efficient and potent night air capability. The year 1964 saw further expansion of this potential and demonstrated even more strongly the evolution of night air operations as doctrine for counterinsurgency.

A Statistical Analysis, 1964

Statistics are often meaningless unless someone takes time to analyze their meaning from a logical and unbiased approach. Statistics contained in the MACV MILREPS are no exception to this premise. Quantities of data are presented in easy to understand form, but it is left to the reader of the MILREPS to determine just what the figures mean and how they should be interpreted. There is always a danger that the analyst may misinterpret or purposely juggle data to support pre-conceived conclusions. There is also a possibility that data which does not support a thesis may simply be excluded from the analysis. In this

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[36]Questionnaire, Maj. John S. Kark, Inf., USA, USACGSC Student, 19 Nov 64.

particular analysis, the author has extracted all available data from the reports and presented it in raw form on charts which were then analyzed to determine what trends or conclusions might be drawn. Conclusions have been made only after careful consideration of all factors which had a bearing on reported night air activities.

The MACV MILREPS were chosen as the basis for a statistical examination of night air operations in Vietnam primarily because they represent the only available documents, in a standardized form, containing appropriate material which may be reduced to analyzable terms. The MILREPS are weekly consolidations and summarizations of daily operational activity and situation reports submitted by Army, Air Force, Navy, and Marine units and detachments throughout Vietnam. As such, they contain some editorializing. However, data on aircraft status, sorties, and missions is considered accurate, as is data on ground operations.

Unfortunately, from the historian's standpoint, detailed record keeping and precise documentation of military activity in Vietnam has been undertaken only recently. The Aircraft Losses Operations Analysis Working Group prefaced their mid-1964 study on minimizing aircraft losses from ground fire with the statement:

> The greatest limitation encountered by the working group was a lack of sufficient data in similar form. Each service maintained different types of records and the information was not easily translatable into common terms.[37]

The MACV MILREPS in their present standardized (but still changing) form are only a year old as of the writing of this paper. The

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[37]Aircraft Losses Operations Analysis Working Group, "Minimizing Aircraft Damage and Losses from Enemy Ground Fire" (Saigon, Vietnam: U. S. Military Assistance Command, Vietnam, 30 Jul 64), p. 4. MACV Directive 335-7 standardized service-wide reporting of antiaircraft fires and hits, but this directive was not implemented until 17 Jan 64.

first report was published as of 21 March 1964 and contained data for the ten day period from 11 March through 21 March. Subsequent reports cover a single week's activities.

Data contained in the charts on the following pages covers the period from 11 March 1964 through 31 January 1965. It was during this forty-six week period that tactics and techniques for night air operations which had been slowly developing during 1962 and 1963 began to evolve as doctrinal employment in counterinsurgency warfare.

Each of the charts is prefaced by a brief statement of the purpose of the chart, a discussion of the apparent trend(s) which the data illustrates, additional factors which might influence these trends, and one or more conclusions which may be drawn from this analysis. The chapter will conclude with a final analysis of the meaning and overall conclusions which may be drawn from the data presented.

Chart 1

NIGHT ATTACKS ON NEW RURAL LIFE HAMLETS (NRLH'S)
AND OUTPOSTS

Purpose: To illustrate total number of VC night attacks per week on NRLH's and outposts.

Apparent trend: The overall trend appears to be preceptibly downward.

Factors influencing the trend: The alternating peaks and valleys of activity illustrate the apparent centralization of VC planning and execution of attacks on a country-wide basis. Periods of extreme activity followed by lulls are characteristic of Viet Cong tactics.

Because the monsoon season does not affect the entire country during any one period, weather apparently does not have an important influence on the trend. The VC may shift their activities from one part of the country to another to take advantage of whatever weather conditions they desire for an attack.

The political coups which took place during this forty-six week period undoubtedly influenced the VC attack plans. (The dates of the coup d'etat were 13 August, 1 November, 26 December 1964, and 20 January 1965.) One trend which is noticeable in all of the charts is reduction in enemy and friendly military activity during the weeks immediately following a coup. This is considered to be due to the "wait and see" attitude of both parties to the conflict. As each newly formed government began to stabilize, the pattern of military action again began to rise.

Conclusions: If we discount the relatively abrupt changes in numbers of attacks following the coups, the average trend is still downward. On the basis of the trend contained in this chart we might conclude

that the VC are becoming more reluctant to attack NLRH's and outposts at night, or that their emphasis is slowly shifting to other more lucrative tactics.

CHART 1

NIGHT ATTACKS ON NEW RURAL LIFE HAMLETS (NRLH) AND OUTPOSTS

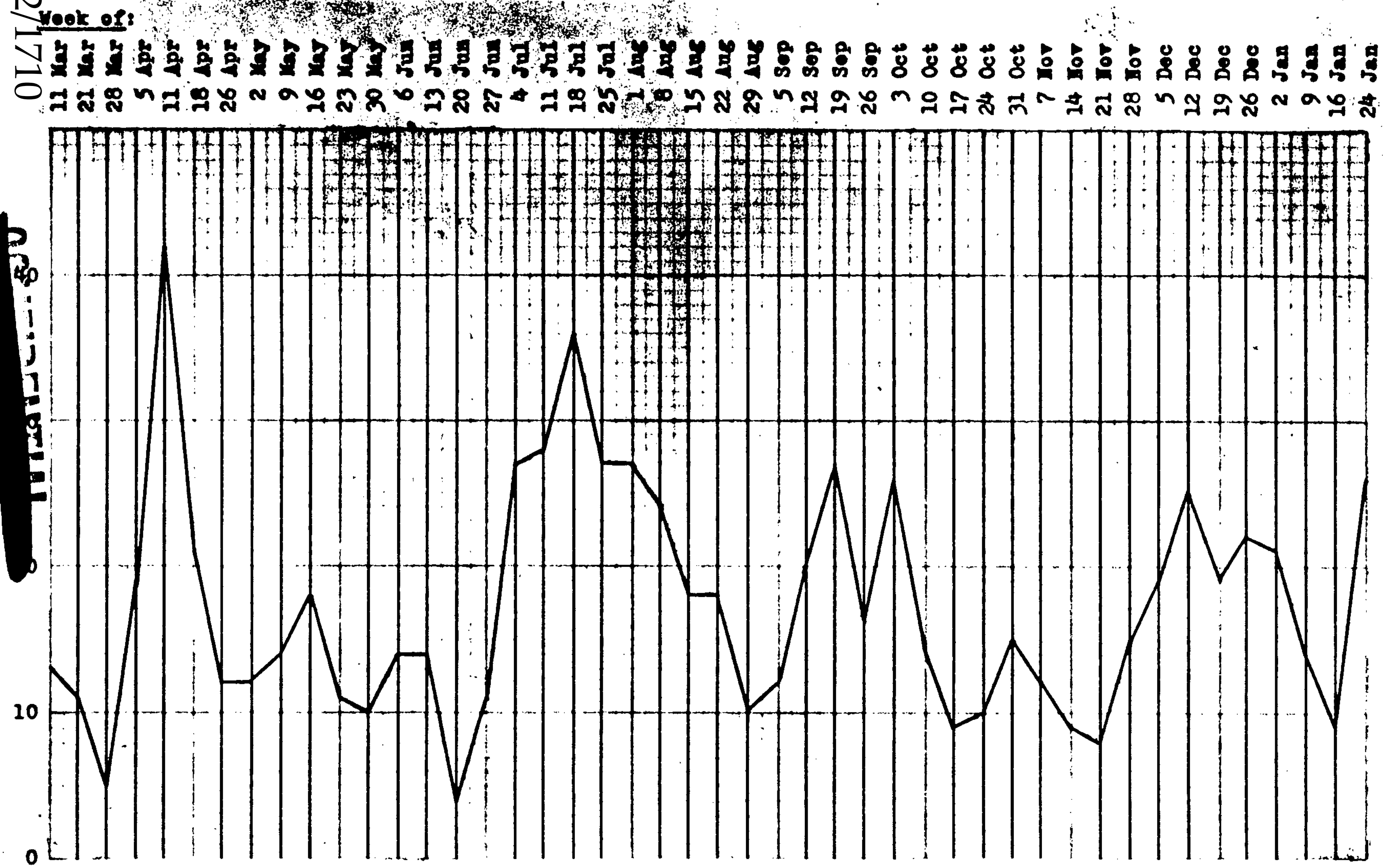

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Chart 2

FLARESHIP RESPONSE TO VC ATTACKS
ON NLRH'S AND OUTPOSTS

Purpose: To illustrate the relative degree to which flareships responded to night attacks on NLRH's and outposts.

Apparent trend: Prior to 1 May 1964, attacks consistently exceeded the numbers of flareships responding. Subsequent to the week of 16 May 1964, however, total flareship tasks equal or surpass total attacks by relatively significant numbers. Attacks totaled 806 during the 46 week period, while flareship tasks totaled 1047. The overall trend in requirements for flareships in support of defensive operations also appears to be downward. This is considered a natural trend in view of the downward trend in attacks.

Factors influencing the trend: At the beginning of 1964, night air operations in Vietnam were keyed primarily to response to VC night attacks on NLRH's and outposts. The format in which the MILREPS present the night flare and fighter support reflects this emphasis. The emphasis was apparently exerted at the operator levels which may account for the success indicated in providing flareships to all facilities reporting attacks during the last seven months of 1964. It should be noted that the flareship response is measured in tasks rather than sorties. On numerous occasions, one flareship provided flare support to more than one hamlet or post under attack, thereby performing two or more tasks.

Conclusions: There are several conclusions which might be drawn from this chart. One is the apparent emphasis that was placed on providing flareships for all hamlets and outposts under attack

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subsequent to the middle of May. The other conclusion which might be made is that increased use of flareships has been one of the factors causing reduction in attacks, or at least has aided in maintaining the frequency of attacks at a controllable level. Major Gorvad, a Special Forces "B" Detachment Commander in IV Corps Tactical Zone, whose experience in Vietnam was primarily during the early months of 1964, supported this latter conclusion in his questionnaire when he stated:

> I had approximately 11 requests for flareships for my camps . . . the illumination support was outstanding and, while I realize there is a great difference in cost between a mortar round and a flare round, it enabled our gunners to fire HE and WP with their mortars rather than illuminating rounds. The flareship would drop, our observers would pick up the targets, and the gunners would fire--worked real well. The bonus effect, of course, was provided by the reluctance of the VC to attack and expose themselves while the area was illuminated. . . . In my opinion, the flareships provided the single most important means in reducing the number of overrun outposts.[38]

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[38]Questionnaire, Maj. Peter L. Gorvad, Inf., USA, USACGSC Student, 19 Nov 64.

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CHART 2

FLARESHIP RESPONSE TO VC ATTACKS ON NLRH AND OUTPOSTS

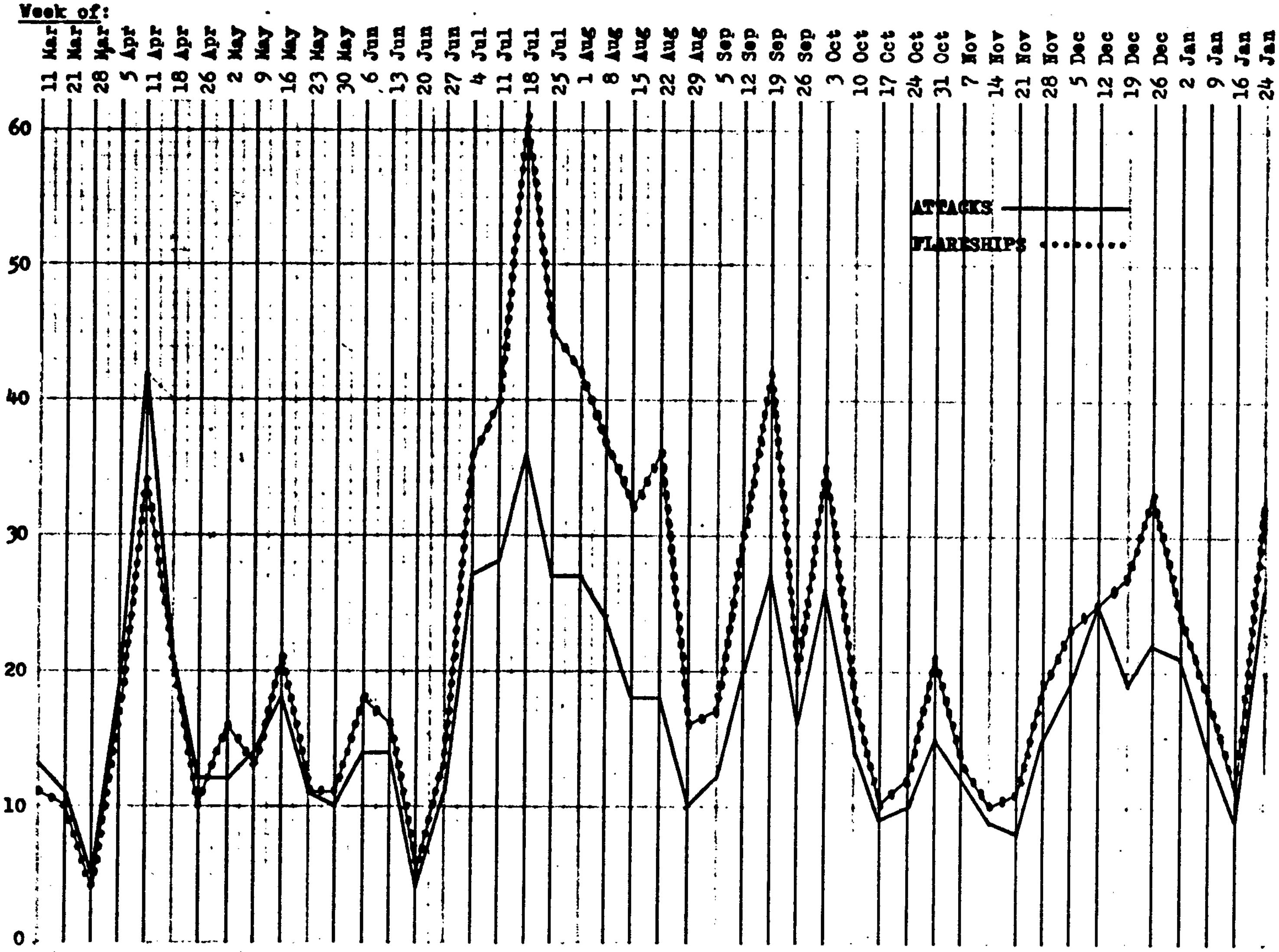

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Chart 3

TOTAL FLARESHIP SORTIES FLOWN

Purpose: To illustrate response of flareships to requests from all operations activities requiring illumination.

Apparent trend: The overall trend in use of flareships is definitely upward.

Factors influencing the trend: Again, periods immediately following coups show marked decreases in flareship activity. The unsettling effect of the coups on all military operations is readily apparent in this chart. The increased number of aircraft available for use in flare missions as the year progressed also undoubtedly contributed to the upward trend in sorties flown.

Conclusions: In comparison with Chart 2, which showed a downward trend in flareship utilization for support of outposts under attack, Chart 3 illustrates the increase in overall flareship operations and represents a significant trend toward greater utilization of flareships in support of offensive operations. As more flareships were relieved of the requirement to support beleagured outposts, they were apparently being utilized more fully in offensive actions. During the first half of this 46 week period, total flareship sorties exceeded flareships required to support hamlets and posts under attack by only 15 sorties. During the second half of the period, 250 sorties were flown in excess of those called for to support defensive operations. These statistics strongly support the thesis that night air operations are evolving as doctrine in counterinsurgency warfare.

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CHART 3

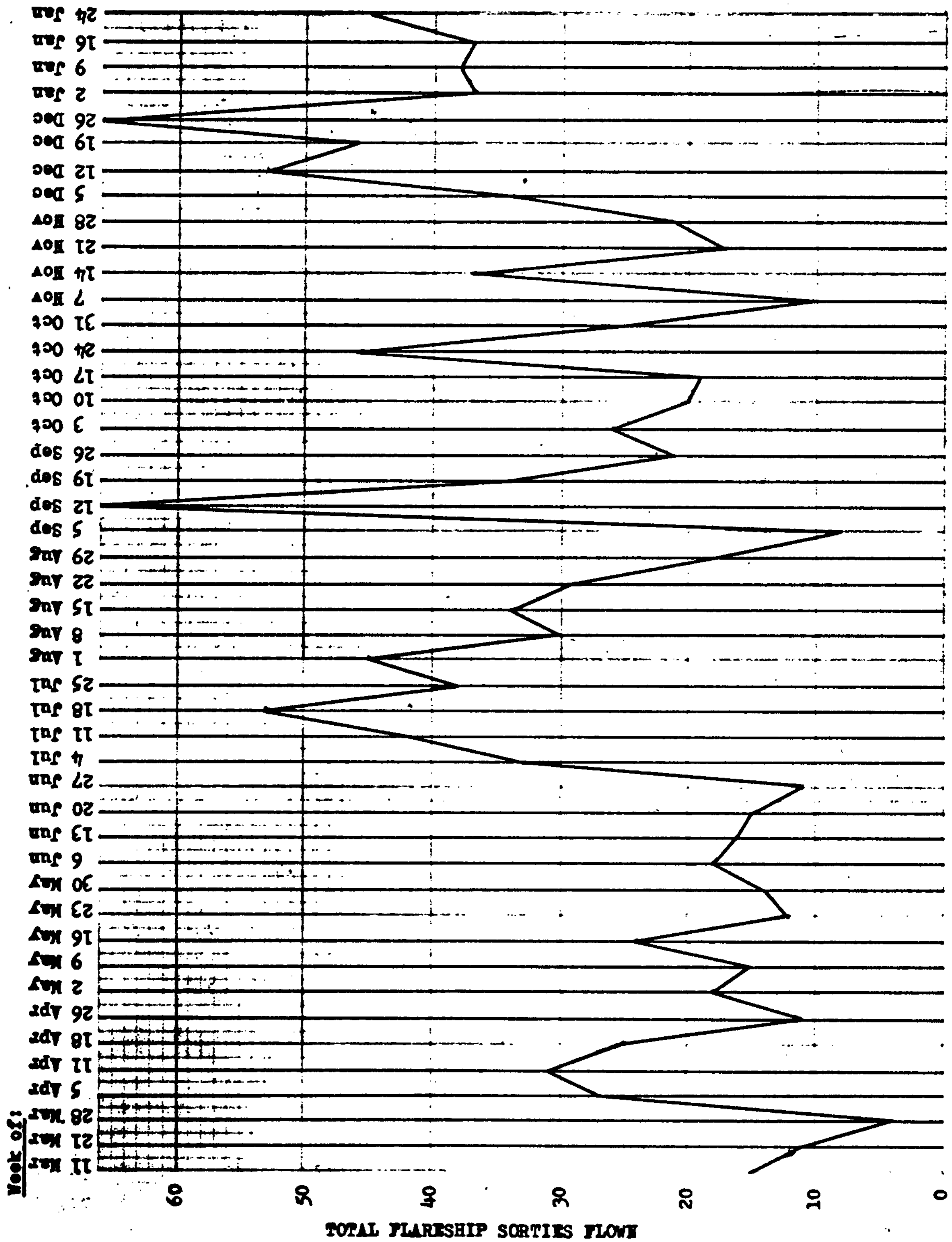

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Chart 4 UNCLASSIFIED

STRIKE AIRCRAFT SUPPORT TO
NLRH'S AND OUTPOSTS

Purpose: To illustrate the relative degree to which strike aircraft responded to night attacks on NLRH's and outposts.

Apparent trend: The only trend readily discernible is the lack of consistency from week to week in providing strike aircraft to assist NLRH and outpost defenders. We might consider that the general trend of strike aircraft utilization is downward on this type of mission, however, as illustrated in Chart 2, this trend simply follows the downward trend of attacks. Strike aircraft sorties flown at night in support of defensive ground operations totaled 815; an average of slightly more than 1 sortie per attack (815 sorties versus 806 attacks).

Factors influencing the trend: Availability of strike aircraft for night operations is largely dependent on the daytime level of flying activity. During the summer months (July, August, September), daytime weather conditions in the delta region of South Vietnam are not conducive to a great amount of air activity; therefore, during this time period more aircraft may have been available to respond to requests for support during the better flying conditions of the night. The significant low in strike aircraft support which occurred during the first two weeks of November was undoubtedly caused by the state of military and political upheavel associated with the VC attack on Bien Hoa Airfield and the two day coup which took place on the first and second of November. All air activity was halted for four days immediately following this coup.

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Conclusions: One conclusion which may be drawn from this comparison is that periods of intensive strike aircraft activity tend to deter VC attacks during several subsequent weeks. When strike aircraft are not provided for each hamlet or outpost under attack, the following weeks appear to bring a greater number of attacks. Strike aircraft, in conjunction with flareships, provided they are used consistently, may be a significant deterent to VC night attack.

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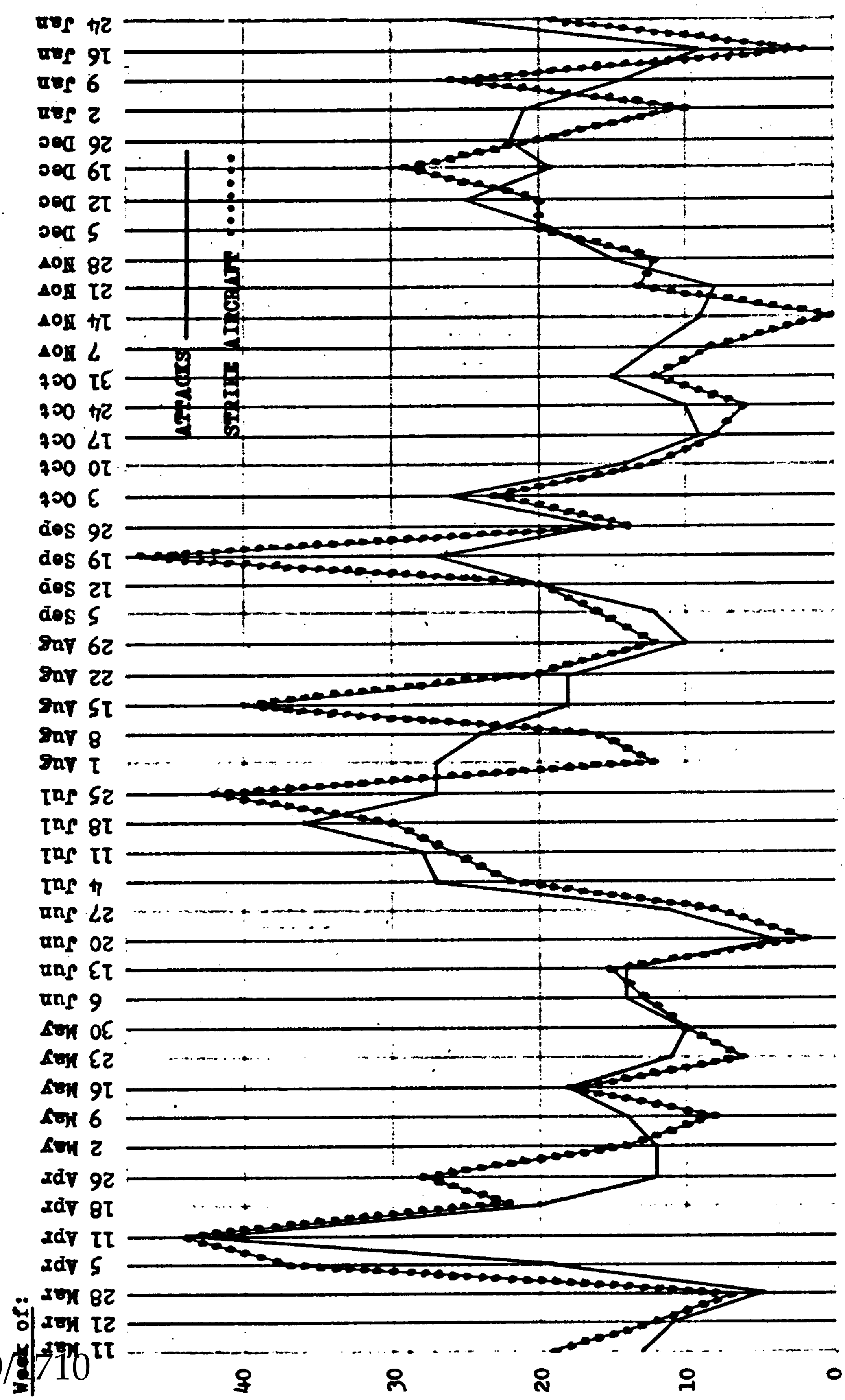
CHART 4

STRIKE AIRCRAFT SUPPORT TO NLRH AND OUTPOSTS



For comparison purposes it would be desirable to have a chart which illustrated the total night air activity by strike aircraft. Conclusions might then be drawn on a statistical basis, which supported the increased use of strike aircraft in offensive as well as defensive night air operations. Unfortunately, statistical data in the MILREPS does not differentiate between day and night air activity other than in the data presented on air support to NLRH and outposts, which is all defensive in nature. Strike aircraft sortie statistics are combined in four categories: close air support, interdiction, armed reconnaissance, and air cover. No breakout of day versus night operations is made.

To document the fact that considerable numbers of night strike sorties of an offensive nature have been flown, we were forced to turn to the narrative portion of the MILREPs. Typical comments which indicate a significant night offensive air effort follow:

> A LARGE SCALE NIGHT OPERATION WAS FLOWN IN THE EARLY MORNING HOURS OF 29 MARCH [1964] WHEN COL. KY, THE VNAF COMMANDER, LED 16 FIGHTER BOMBERS ON A BOMBING STRIKE AGAINST A VC CONCENTRATION AT YC610530.[39]

At 120500 April 1964 during Joint Operation PHUONG HOANG, "ARTILLERY, FLARESHIP, AND CLOSE AIR SUPPORT WERE FURNISHED. VNAF AND USAF FLEW 10 STRIKES AND TWO FLARESHIP SORTIES, REPORTEDLY KILLING 5 VC."[40] The MILREP for the week of 20-27 June 1964 stated that, "THE COMBAT AIR ACTIVITY WAS HIGHLIGHTED BY A 14 AIRCRAFT (A-1H) NIGHT ATTACK ON A VC CONCENTRATION IN I CORPS ON THE NIGHT OF 23 JUN 64."[41] During the

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[39] USMACV, op. cit., MILREP Week of 28 Mar 64, p. 10.

[40] Ibid., MILREP Week of 11 Apr 64, p. 11.

[41] Ibid., MILREP Week of 20 Jun 64, p. 14.

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week of 4-11 July 1964, the ARV[redacted] CHINA NGHIA 36. This was the first operation in which armed Army helicopters were used for suppressive fire support at night. The action was described as follows:

> AT 1735 A REQUEST FOR U. S. ARMY ARMED HELICOPTERS WAS RECEIVED THROUGH THE VNAF AIR REQUEST NET. THE REQUEST WAS SIMULTANEOUSLY PROCESSED BY ARMY AND VNAF. TWO VNAF A-1H AIRCRAFT WERE AIRBORNE AT 1805, REPORTED THEY COULD NOT ESTABLISH RADIO CONTACT, RETURNED TO BASE AND LANDED WITH ORDNANCE. U. S. ARMY AVIATION FLEW 64 ARMED HELICOPTER SORTIES WITH THE FIRST TWO SORTIES AIRBORNE AT 1745. SUPPRESSIVE FIRE MISSIONS WERE FLOWN CONTINUOUSLY UNTIL 0200 WHEN WEATHER FORCED A TWO HOUR DELAY. AT 0400 SUPPRESSIVE FIRE MISSIONS WERE RENEWED AND CONTINUED UNTIL 0815. . . . AT 2015 THE FIRST OF FIVE FLARE AIRCRAFT (2 VNAF, 3 USAF) ARRIVED IN THE AREA. WITH THE EXCEPTION OF TWO HOURS, FLARE SUPPORT WAS DELIVERED THROUGHOUT THE NIGHT WITH A TOTAL OF 297 FLARES BEING DROPPED.[42]

The MILREP further commented on this operation and observed that,

> THE EXTENSIVE FLYING PERFORMED DURING THE NIGHT OF 10-11 JULY BY ARMY HELICOPTERS IS AN INDICATION OF THE GROWING CAPABILITY OF ARMY AVIATION TO RENDER SUPPORT DURING HOURS OF DARKNESS. THIS COULD PROVE TO BE VERY VALUABLE TO GVN FORCES IN FUTURE NIGHT OPERATIONS AGAINST THE VC.[43]

Several other specific references indicate additional utilization of armed helicopters for night offensive air support. These operations were conducted during the week of 18-25 July 1964.

> ARMED HELICOPTERS FROM THE UTT COMPANY ESCORTED TRANSPORT HELICOPTERS IN THE III CORPS TACTICAL ZONE ON A NIGHT RESUPPLY MISSION, AND ENGAGED HOSTILE GROUND FORCES WHILE THE UH-1B SUCCESSFULLY COMPLETED THEIR OFF-LOADING OPERATIONS.[44]
>
> . . . .
>
> THE COMBINED FORCES OF THE OPERATION LAUNCHED AN ATTACK AT 2000 HOURS TO RECOVER THE FIVE M113 CARRIERS THAT HAD BEEN PROTECTED BY TWO INFANTRY PLATOONS. WITH THE AID OF THE ILLUMINATION PROVIDED BY VNAF AND THE SUPPRESSIVE FIRE OF TEN U. S. ARMY ARMED HELICOPTERS, THE FIVE M113 WERE EVACUATED BY 2115 HOURS.[45]

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[42] Ibid., MILREP Week of 4 Jul 64, pp. 10-11.

[43] Ibid., p. 12.

[44] Ibid., MILREP Week of 18 Jul 64, p. 3.

[45] Ibid., p. 13.

During the week of 25 July-1 August 1964 the following night offensive air operation was reported:

> ON THE EVENING OF 30/31 JULY 64, THE VNAF PLANNED AND LAUNCHED A NIGHT STRIKE AGAINST A SECRET VC AMMUNITION DUMP AND TROOP CONCENTRATION IN BIEN HOA PROVINCE (YT060190). DURING THE PERIOD 302245H TO 310025H JULY, A VNAF FLARESHIP ILLUMINATED THE AREA BY DROPPING 29 FLARES. THEN A FLIGHT OF FOUR VNAF A-1H USING NAPALM AND WHITE PHOSPHOROUS BOMBS ATTACKED THE TARGET BETWEEN 2305H AND 2335H. THIS STRIKE FOLLOWED AT 2355H WITH A SECOND ATTACK BY TWO A-1E EMPLOYING THE SAME GENERAL ORDNANCE LOADS. ALTHOUGH THE RESULTS WERE OBSCURED BY DARKNESS, THREE LARGE SECONDARY EXPLOSIONS WERE REPORTED IN THE TARGET AREA.[46]

During October, additional night missions of an offensive nature were flown.

> TWO SPECIAL NIGHT MISSIONS WERE SCHEDULED FOR WAR ZONE C, AND BOTH WERE COMPLETED. ONE MISSION CONSISTING OF A VNAF C-47 FLARESHIP AND 2 VNAF A-1H PROCEEDED FROM THE CITY OF TAY NINH NORTH ALONG HIGHWAY 22 SEARCHING FOR VEHICULAR TRAFFIC. . . . THE SECOND MISSION, A FLIGHT OF THREE USAF A-1E, DROPPED ORDNANCE ON SELECTED TARGETS, BUT THE RESULTS WERE UNOBSERVED.[47]
>
> . . . .
>
> ON 4 OCTOBER . . . HELICOPTERS PERFORMED VISUAL SURVEILLANCE AND SUPPRESSIVE FIRE MISSIONS THROUGHOUT THE AFTERNOON AND EVENING UNTIL 2300 HOURS.[48]
>
> FOUR NIGHT FLARE MISSIONS WERE CONDUCTED IN BINH DINH PROVINCE DURING THE WEEK. MISSIONS WERE CONDUCTED ALONG ROADS AND RAILROADS BY AIRCRAFT OF THE 52ND AVN BN WITH THE OBJECT OF DETECTING VC MOVEMENT OR AMBUSH EFFORTS.[49]
>
> NIGHT SURVEILLANCE MISSIONS WERE CONTINUED IN I AND II CORPS TACTICAL ZONES, ALONG THE COASTAL RAILROAD AND HIGHWAY NUMBER 1, TO REPORT ON VC SABOTAGE ACTIVITIES.[50]

Although these latter two operations are not truly offensive in nature, they do represent night air <u>action</u> rather than <u>re</u>action. During the

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[46] <u>Ibid.</u>, MILREP Week of 25 Jul 64, pp. 11-12.

[47] <u>Ibid.</u>, MILREP Week of 3 Oct 64, p. 14.

[48] <u>Ibid.</u>, p. 15.

[49] <u>Ibid.</u>, MILREP Week of 17 Oct 64, p. 13.

[50] <u>Ibid.</u>, MILREP Week of 24 Oct 64, p. 3.

[redacted]

first week in November 1964, primarily in response to the VC attack on Bien Hoa, the VNAF conducted significant night offensive air operations.

> BETWEEN 070155H AND 071120H NOV VNAF A-1H FIGHTER-BOMBERS FLEW A TOTAL OF 45 ID /interdiction/ SORTIES AGAINST VC CONCENTRATIONS IN ZONE D. A TOTAL OF 82 TONS OF GP AND FRAGMENTATION BOMBS AND 10,000 ROUNDS OF 20MM WERE EXPENDED. PILOT REPORTS TARGET AREA OBSCURED BY DARKNESS AND TREES.[51]

USAF aircraft also participated in this "get even" operation. Eight A-1E's dropped 18.4 tons of GP and WP bombs.

Due to the fact that the MACV MILREPS include narrative comments only on major ground and air operations, it is impossible to accurately determine the number of night offensive air sorties flown during 1964. However, the operations which were mentioned show a decided trend by the VNAF, USAF, and U. S. Army Aviation toward utilizing more fully the hours of darkness for offensive as well as defensive operations. This is a key trend which supports evolving doctrine for exploitation of night air operations in Vietnam.

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[51] _Ibid._, MILREP Week of 31 Oct 64, p. 11.

[redacted]

Chart 5

TOTAL FLARES DROPPED IN SUPPORT OF
ALL NIGHT AIR OPERATIONS

Purpose: To illustrate the actual numbers of flares dropped in support of NLRH's and outpost defense, and to compare these figures with a hypothetical number of flares dropped in support of offensive air operations.

Apparent trend: The solid line on this chart shows the number of flares actually dropped in support of NRLH's and outposts under night attack. No significant trend or characteristic other than wide variation in numbers of flares dropped from week to week can be noticed. The pattern follows the pattern of attacks. The dashed line indicates the sum of flares actually dropped on defensive missions and the number of flares which we computed could and should have been dropped from flareships on offensive air missions. These latter figures were computed by dividing the total flares actually dropped (55,715) by the total defensive flareships (1047); an average of 53.2 flares dropped per flareship. We then multiplied the weekly flare sorties, in excess of those flown in support of defensive operations, by 53.2 to determine a weekly projected flare drop figure for offensive flareships. It is recognized that this is highly conjectural, nevertheless, with no other accurate means to determine the actual flares dropped, this technique of computation is considered to be the most realistic possible and the results are felt to be reasonable. The trend in the total flares dropped (dashed line) is unmistakably upward. This trend is defensible in view of the many MILREP references to offensive night

air operations during the latter half of the 46 week period. The one extreme figure (4370), during the week of 12-19 September, was compiled during a period of extensive night operations. The MILREP for that week stated:

> THE C-123 FLARESHIPS WERE USED EXTENSIVELY THROUGHOUT III AND IV CTZS THIS WEEK IN RESPONSE TO A THREEFOLD INCREASE IN REQUIREMENTS FOR FLARE SUPPORT.[52]

<u>Factors influencing the trend</u>: In computing total flare figures we have not adjusted for the possibility that offensive air operations may require more or less flares per operation than defensive operations. No adjustment was made because no constant factor will necessarily apply, and there is no source in history from which we may extract experience factors for flare support in counterinsurgency.

The factor of weather undoubtedly influenced the trend, but again to what degree is difficult if not impossible to determine. Over a period which is very nearly a full year, it is felt that the factor of weather will become neutral insofar as the long range trend is concerned.

<u>Conclusions</u>: There are several conclusions which may be drawn from this chart. There was a definite increase in night illumination being provided for combined defensive and offensive ground operations during the last six months of the time period under consideration. When we consider that each air dropped flare provides illumination for approximately 3 minutes, and that an average of 217 flares were dropped each night of the 46 week period (total flares = 69,813 ÷ 322 days = 217 flares per day), theoretically, at least, we provided a capability which could have illuminated one point continuously every minute of darkness during the entire 46 week period.

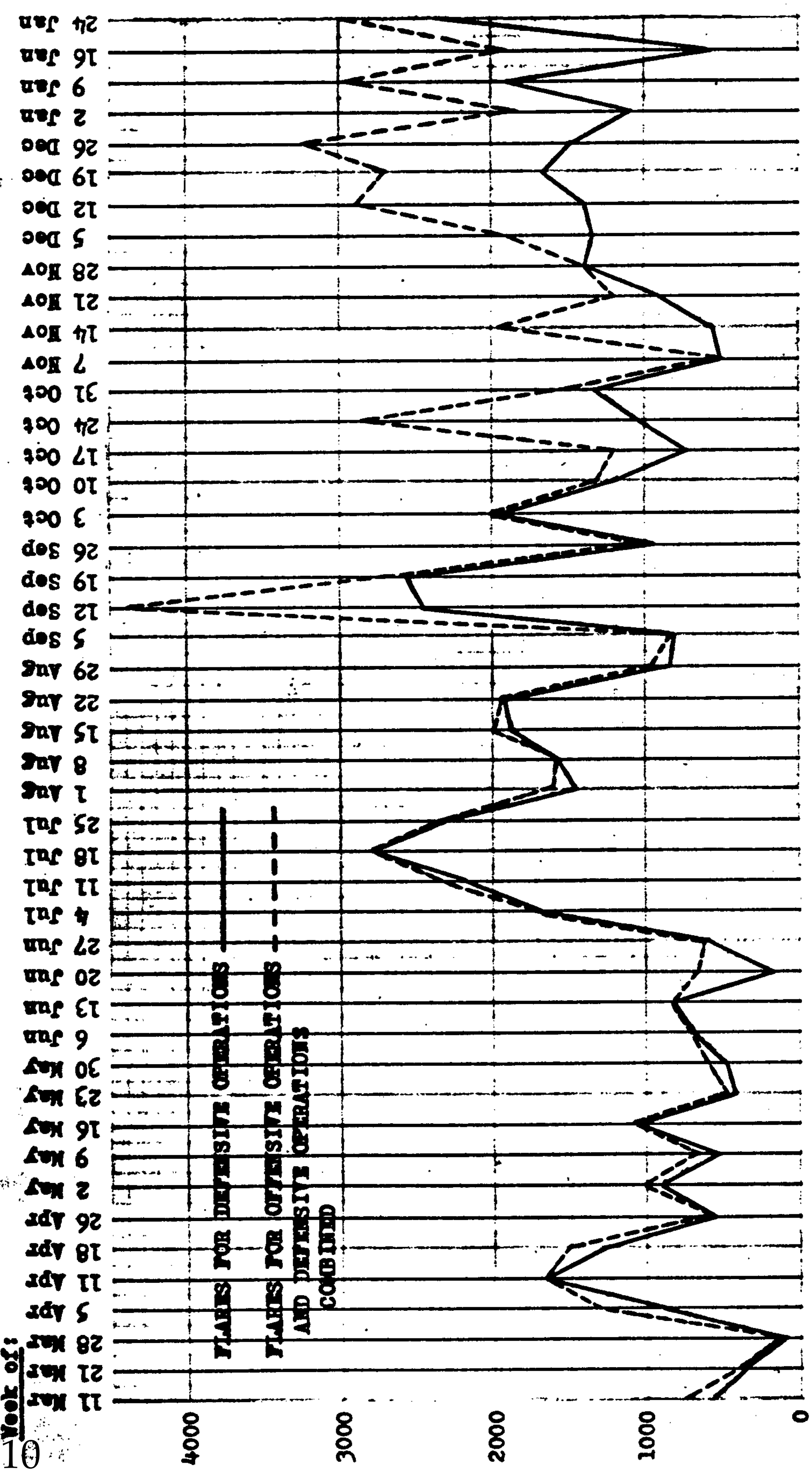
[52] <u>Ibid.</u>, MILREP Week of 12 Sep 64, p. 17.

This is obviously an impracticality for many reasons, however, this mathematical exercise illustrates dramatically the scope and significance of the night illumination effort conducted during 1964.

 [redacted]

CHART 5

TOTAL FLARES DROPPED IN SUPPORT OF ALL NIGHT AIR OPERATIONS



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TOTAL AIR TASKS

Purpose: To illustrate weekly totals of air tasks flown in Vietnam during 1964 by all services (solid line), and a breakdown of air tasks flown by USAF/VNAF aircraft (dotted line) in relation to air tasks flown by U. S. Army and Marine Corps aircraft (dashed line). This chart should be examined comparatively with Chart 7.

Apparent trends: The first half of the forty-six week period shows very little overall change in total air tasks or in tasks flown by either the Air Forces or Army/Marine forces. However, beginning about 1 September 1964, the trend for both air force and army air activity is noticeably higher; almost doubling during the following ten week period, and tripling its original level during the final ten weeks of the period. Total tasks flown by USAF/VNAF equaled 104,688. The U. S. Army/Marine Corps tasks totalled 186,366. Again it should be noted that these are tasks and not sorties. There is one discrepancy in these figures however, due to the fact that VNAF reports only one task per sortie while USAF and U. S. Army/Marine Corps units may accomplish and report more than one task per sortie.

Factors influencing the trends: The increased input of aircraft, equipment, and personnel during the late summer months of 1964 obviously influenced the overall air activity of all services from that time forward. Improving weather conditions in the VC infested delta region, after the summer monsoon, undoubtedly may be credited for some of the increase in air activity. The coup influence is

noticeable particularly during the first week in November when all air activity was curtailed for a four day period.

Conclusions: There is only one conclusion which may be drawn from this chart, and that is the obvious increase in overall air activity by all services during 1964. This increase should be kept in mind when examining Chart 7 which deals with service participation in night aerial illumination tasks.

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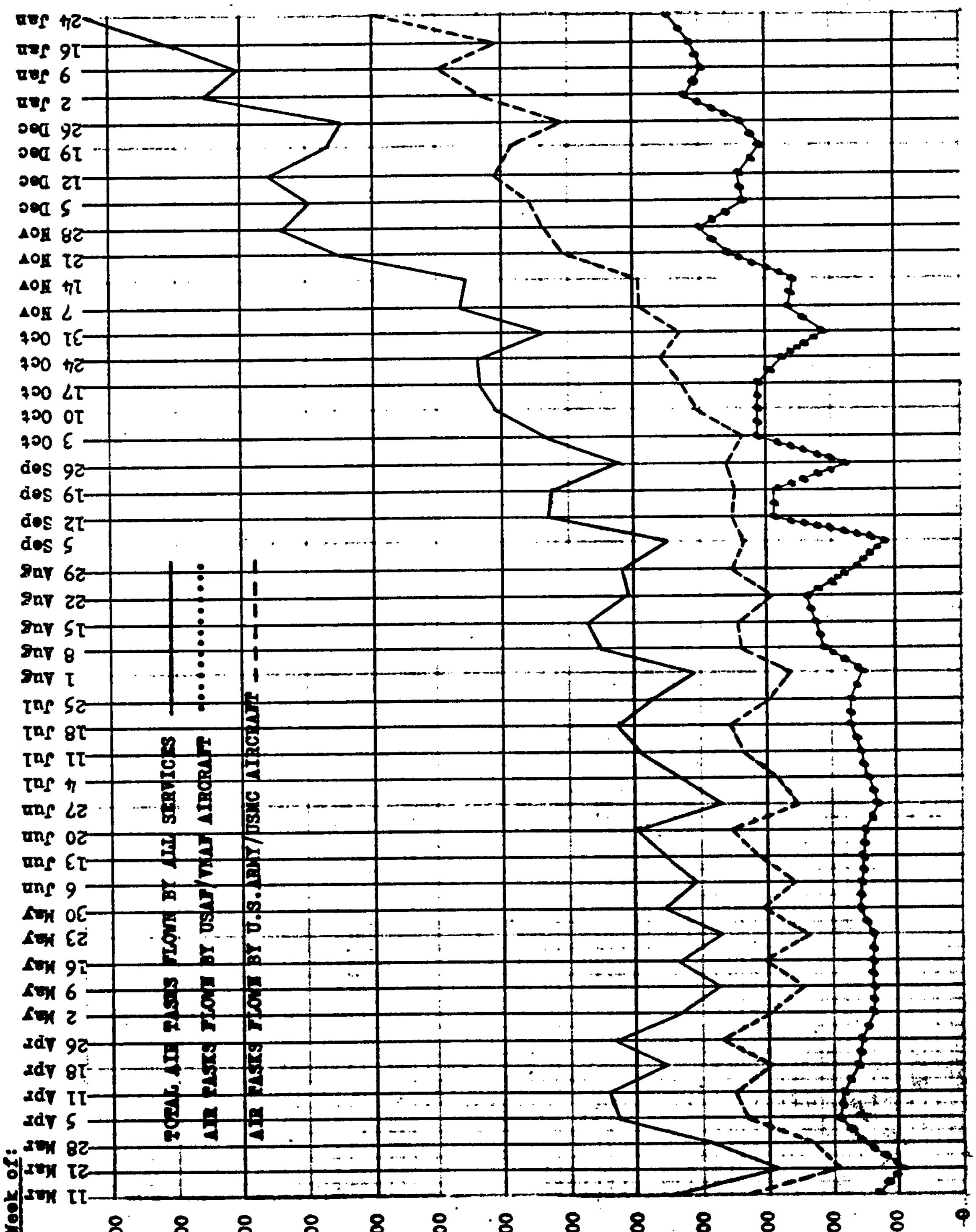
CHART 6



TOTAL AIR TASKS

[redacted]

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Chart 7

A COMPARISON OF FLARE DROP TASKS

Purpose: To illustrate the comparative participation in flare drop tasks by USAF/VNAF (dotted line), and U. S. Army/Marine Corps (dashed line) aircraft. This chart should be examined with reference to Chart 3 which illustrated total flareship sorties. (This reference should not be a direct comparison as we cannot equate tasks with sorties, however, the overall trends are comparative in nature.)

Apparent trend: Approximately 1 July 1964, U. S. Army aircraft begin to appear frequently in flare drop missions. Several instances are noted where a decrease in USAF/VNAF flareship tasks was compensated for by a corresponding increase in Army flareship tasks (weeks of 14-21 November 1964 and 9-16 January 1965). The overall trend of flare drop activity, particularly for Army aviation, is noticeably upward during the final months of 1964. USAF/VNAF performed a total of 1133 flare drop tasks while the U. S. Army/ Marine Corps total was 162.

Factors influencing the trend: Although there was a definite increase in USAF/VNAF flareship activity during 1964 over previous years, there have still been instances reported when flareships were not available when needed due to other commitments. The U. S. Army, recognizing this problem, apparently attempted to solve it by providing airborne illumination from their own sources. There can be little doubt that this recourse had a favorable impact on the success of a number of offensive as well as defensive air support

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operations at night. If, in addition, we consider the amount of unreported flare dropping conducted by TO-1 aircraft under divisional control, the Army aviation emphasis on illumination and night air operations should be considerably greater than indicated in the MACV MILREP statistics.

Another factor which may well have influenced the Army's increased flare drop activity is the comparative lack of helicopter mission degradation caused by weather conditions. When weather prevents C-47 or C-123 flareships from operating at low levels, a helicopter may still be capable of performing its mission with relative safety and effectiveness.

<u>Conclusions</u>: There has been a rapid increase in emphasis by U. S. Army aviation on the employment of aerial illumination. This is the major conclusion which we may draw from the statistics in Chart 7. This emphasis is a cause, and a result, of the overall increase in air activity in Vietnam during the hours of darkness, and is one of the major <u>changes</u> in emphasis which indicate an evolving doctrine for counterinsurgency.

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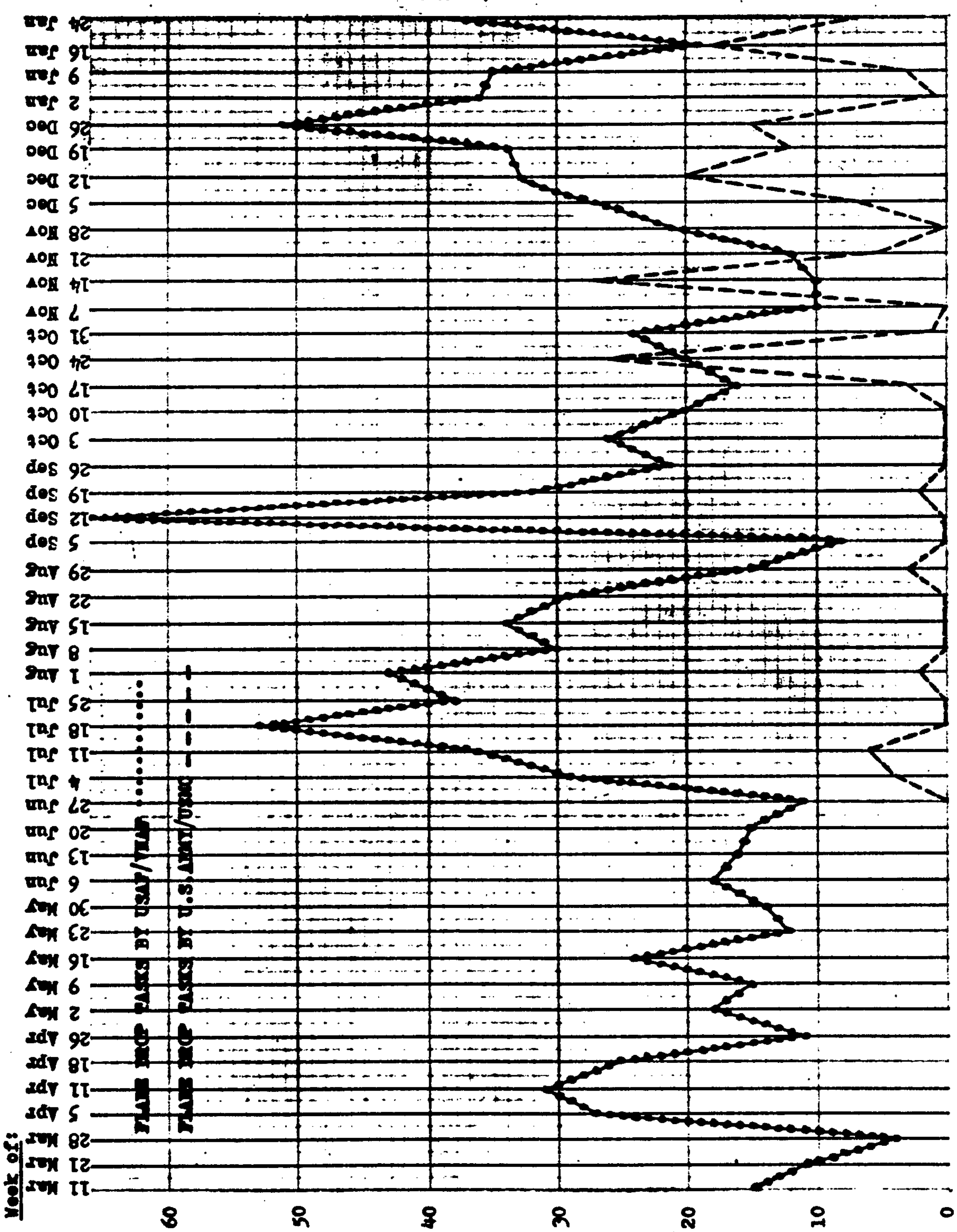
CHART 7



A COMPARISON OF FLARE DROP TASKS

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An overall examination and analysis of the foregoing charted data and conclusions drawn therefrom leads directly to a final conclusion, i.e., the statistical history of night air operations in Vietnam during 1964 points unerringly toward an evolving doctrine for counterinsurgency which makes full use of all facets and capabilities of air power during the hours of darkness. The trends are unmistakable. It remains only for future counterinsurgent forces to exploit the experience gained in night operations on the ground and in the air over Vietnam and to accept, as doctrine, the use of the night.

[redacted]

CHAPTER IV

HARDWARE, HIGHLIGHTS, AND HAZARDS

A discussion of operational factors which influence a military action and which also indicate an evolving military doctrine would not be complete without consideration of specific equipment, tactics, and techniques which make that operation feasible and militarily productive. In this case, the operation is conducted at night, in the air, in a counterinsurgency environment, and as such, presents especial problems in the realms of hardware and tactical action. The past and present extent of night air operations in Vietnam has been covered in detail, and certain conclusions have been made regarding feasibility and productivity. It now remains to cover, in general terms, airborne and related ground equipment utilized in Vietnam to support these operations. Evolution of tactics and techniques for employment of aircraft at night will also be discussed along with those tactics which have been used with success in other counterinsurgency wars and which contributed to development of our current tactics. Finally, consideration will be given to reduced vulnerability of aircraft to ground fire when operating at night.

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Tools of the Trade for Nighttime
Counterinsurgency

Development and expansion of night air activity in Vietnam has been primarily in the field of operations and tactics. Development of military hardware to support this increased activity has progressed at a comparatively slower rate. The majority of aircraft which contributed and still contribute to steadily improving effectiveness of night air operations have been conventionally powered and, relatively speaking, obsolete or obsolescent. Much of the support equipment for air operations has been in the same category. The predominant use of conventional aircraft and unsophisticated ground support equipment was dictated by a number of practical considerations. To cite a few: legally, the Geneva Accords of 1954 prohibited introduction of jet aircraft into Vietnam; pragmatically, there were few targets during 1962 and 1963 which warranted the tremendous firepower of modern and costly jet fighter-bombers (suitable targets, in the form of larger concentrations of Viet Cong, began to develop during 1964); and logistically, short runways and inadequate facilities to support jet operations, plus the relatively high cost of supplying and maintaining jet fighter-bomber units mitigated against their deployment and employment during the initial air forces buildup.[1]

The scope of this thesis does not permit a deeper probe into economic or political aspects and implications of air power as it is being used in Vietnam during these first few months of 1965. However, militarily, continued and significant increases in night air operations

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[1]In 1962, Tan Son Nhut airport, in Saigon, had the only runway in South Vietnam of sufficient length to handle jet aircraft and the only facilities capable of their support. During 1963 and 1964, airfields at Bien Hoa and DaNang were lengthened to permit jet operations and facilities were constructed to provide for jet maintenance and support.

[redacted]

and employment of more sophisticated aircraft and weapons may become necessary due to enemy antiaircraft capabilities and possible interjection of an enemy threat to our complete air superiority. We may then find that the advantages of night air operations become more profound and realize even greater results. Employment of air power at night must be given its proper emphasis without regard to the level of military conflict.

The first tool in the trade of night air operations for counterinsurgency is obviously the aircraft. Each aircraft listed in Table 1 (p. 50) is technically capable of flying at night, expending ordnance at night, and/or dispensing illumination devices. Practical considerations, however, have dictated that combat night air support missions be conducted by a limited number of these aircraft. If we list, chronologically, aircraft used extensively for night air support in Vietnam during the January 1962 through January 1965 time period, their employment occurred in the following order and on the following types of combat missions:

Type Aircraft	Type Mission
T-28 (VNAF)	Night air defense
SC-47 (USAF)	Flare drop and psywar broadcast
B-26 (USAF)	Night close air support
T-28 (USAF)	Night close air support
RB-26 (USAF)	Night visual and photo reconnaissance
C-47 (VNAF)	Flare drop
OV-1 (USA)	Night visual, photo, and armed reconnaissance
A-1E (USN)	Night air defense

[redacted]

Type Aircraft (Cont.)	Type Mission (Cont.)
A-1H (VNAF)	Night armed reconnaissance and close air support
T-28 (VNAF)	Night close air support
TO-1D (VNAF & USA)	Night visual reconnaissance, fighter direction (FAC), and flare drop
C-123 (USAF)	Flare drop
A-1E (USAF)	Night close air support
UH-1B/D (USA)	Night armed reconnaissance, flare drop, and suppressive fire
FC-47 (USAF)	Flare drop and night close air support

Although only one type of helicopter is mentioned in this listing (UH-1B/D), it is important to recognize that H-21 (USA) and H-34 (VNAF and USMC) helicopters also played a significant role in night reconnaissance, medical evacuation, and combat support liaison. In addition, light fixed wing aircraft of the Army and Air Force flew countless sorties at night in support of the overall military effort. During this same period there were a number of night photo missions flown by RF-101 reconnaissance aircraft staged initially in Bangkok and then in Saigon. USAF F-102 aircraft were also active in night air defense missions staging from Tan Son Nhut airport in Saigon.

Significant changes in numbers and types of aircraft employed on night missions in Vietnam have occurred primarily during 1964. The workhorse B-26, after several months of increasing non-combat losses, was retired in the latter part of March 1964.[2] The equally rugged but lightly armed T-28 was phased out of the USAF combat inventory the first

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[2]Aircraft Losses Operations Analysis Working Group, "Minimizing Aircraft Damage and Losses from Enemy Ground Fire" (Saigon, Vietnam: U. S. Military Assistance Command, Vietnam, 30 Jul 64), p. B-2-3.

week in July, although the VNAF retained a limited number for reconnaissance and for instrument and proficiency training.[3] Capability to perform night air operations was not reduced by these actions however, due to the rapidly increasing inventory of A-1H's and A-1E's brought into the country during the early spring and summer months of 1964.

> THE VNAF 518TH FIGHTER SQ, WHICH WAS ORGANIZED ON 10 MARCH, FLEW ITS FIRST COMBAT MISSIONS ON 18 MAR 1964. THE VNAF NOW HAS TWO SQUADRONS OF A-1H'S, BOTH STATIONED AT BIEN HOA. THE 514TH POSSESSES 17 AIRCRAFT, AND THE 518TH, SEVEN. EVENTUALLY EACH SQ WILL HAVE 20 A-1H AIRCRAFT.[4]

The MACV MILREP for the week of 25 April 1964 noted some additional changes which were taking place in aircraft status during this period:

> THE FIGHTER STRENGTH OF THE 1ST AIR COMMANDO SQUADRON HAS BEEN INCREASED TO 19 T-28'S. THIS HAS ENABLED IT TO FULFILL THE ESCORT REQUIREMENTS AND ALSO TO FLY A GREATER PROPORTION OF NIGHT CLOSE AIR SUPPORT TASKS. THE NIGHT COMBAT CAPABILITY HAS BEEN ENHANCED WITH TWO EA-1F AIRCRAFT (TWO SEAT A-1H'S EQUIPPED WITH RADAR AND FOUR 20MM CANNON) OPERATING IN AN AIR DEFENSE ROLE UNDER THE TACTICAL AIR CONTROL SYSTEM.[5]

During July 1964, Army helicopters began to play a greater part in night air operations. The MILREP for the week of 11 July stated that,

> ARMED HELICOPTERS CONTRIBUTED GREATLY TO THE AVIATION EFFORT IN III AND IV CORPS TACTICAL ZONES, AND SUPPORTING SPECIAL FORCES

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[3]U. S. Military Assistance Command, Vietnam, "Military Reports," Published Weekly, 11 Mar 64 through 31 Jan 65 (Saigon, Vietnam: U. S. Military Assistance Command, Vietnam, Week of 27 Jun 64), p. 3.

[4]*Ibid.*, MILREP Week of 11 Mar 64, p. 25.

[5]*Ibid.*, MILREP Week of 25 Apr 64, p. 16. (The temporary increase in T-28 inventory was brought about by transfer of VNAF T-28's to the 1st Commando unit as VNAF received A-1H replacements. The EA-1F referred to in this report is now commonly known as the A-1E.)

> OUTPOSTS DURING THE HOURS OF DARKNESS. . . . THE US ARMY HELICOPTERS DID A COMMENDABLE JOB OF MEDICAL EVACUATION DURING HOURS OF DARKNESS ON 14-15 JULY.[6]

In September their night capability was further exploited in air cover missions:

> TWO AIRCRAFT (A-1E) HAD BEEN SHOT DOWN BY GROUND FIRE IN KIEN GIANG PROVINCE, BETWEEN 230030H AND 230100H SEP. ARMED HELICOPTERS OF THE DELTA BATTALION AND AMBULANCE HELICOPTERS OF THE 57TH MEDICAL DET WERE SCRAMBLED AT 230105H SEP AND PROVIDED CONTINUOUS COVER AT THE CRASH SITE UNTIL DAYLIGHT.[7]

A final example of employment of UH-1B helicopters in night operations was contained in the MILREP for the week of 12 December 1964.

> AT 140100H, FIVE ARMED AND ONE CONTROL UH-1B HELICOPTER RESPONDED TO AN OUTPOST UNDER HEAVY VC ATTACK IN THE 9TH DIV AREA. FLARES WERE DROPPED FROM THE CONTROL HELICOPTER TO ASSIST IN DIRECTING ARTILLERY AND SUPPRESSIVE FIRES. THE QUICK RESPONSE OF THE HELICOPTERS ENABLED THE OUTPOST TO REPULSE THE VC ATTACK. ARMED HELICOPTERS ALSO PERFORMED ESCORT MISSIONS FOR ARVN TROOP CARRIERS REINFORCING THE OUTPOST BETWEEN 0330H AND 0500H.[8]

It is perhaps fitting that the aircraft which has performed one of the most important night missions (flaredrop) and the greatest number of night missions is the venerable C-47. In its many configurations, the twenty-five year old "Gooney Bird" continues to be called upon to perform tasks which its designers must shudder to contemplate. Aside from its normal use as a transport, psychological warfare broadcast missions, flaredrop and leaflet drops are common missions for this reliable machine. The ultimate in utilization of the C-47 was realized

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[6] Ibid., MILREP Week of 11 Jul 64, pp. 3 and 9.

[7] Ibid., MILREP Week of 20 Sep 64, p. 14.

[8] Ibid., MILREP Week of 12 Dec 64, pp. 14-15.

during the week of 12 December 1964 when, with a new designation (FC-47), and a few "minor" modifications (in the form of SUU 11/A gun pods),[9] this aircraft was first used as a fighter-bomber.

> ONE FC-47 WAS EMPLOYED FOR THE FIRST TIME. ON 171440H DEC, THE FC-47 FURNISHED CLOSE AIR SUPPORT FOR AN OUTPOST THAT WAS UNDER ATTACK BY STRAFING VC PERSONNEL AND STRUCTURES WITH MORE THAN 14,000 ROUNDS OF 7.62MM AMMUNITION. . . . SUBSEQUENTLY, THIS AIRCRAFT FLEW THREE INTERDICTION SORTIES.[10]

The following week, additional FC-47 activity was reported.

> FLARESHIP ACTIVITY INCREASED SLIGHTLY WITH FC-47 AIRCRAFT BEING UTILIZED FOR BOTH FLARE DROPS AND CLOSE AIR SUPPORT FOR THREE OUTPOSTS UNDER VC ATTACK. GROUND REPORTS FROM TWO OUTPOSTS INDICATE THAT VC BROKE CONTACT AFTER ACTION OF FC-47 WHILE THE VC CONTINUED THEIR ATTACK ON THE THIRD OUTPOST.[11]

The modification and unique employment of the FC-47 is undoubtedly due to the need for an immediate strike capability in support of outposts and hamlets under attack. Throughout the three year period under consideration, flareship response progressively improved; from a posture of ground alert during 1962, to the all-night airborne alert and cover of 1964.[12] However, the related and increasingly necessary fighter support has not had this capability due, primarily, to endurance. There have been repeated instances (particularly since the VC have become stronger and bolder) when flareships have arrived over a beleagured outpost and flares alone have not been an adequate deterrent to continuation of the VC attack. The VC were quick to recognize the usual delay between flares and arrival of firepower, and at times

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[9] Ibid., MILREP Week of 12 Dec 64, p. 2.

[10] Ibid., p. 11.

[11] Ibid., MILREP Week of 19 Dec 64, p. 11.

[12] Ibid., MILREP Week of 26 Dec 64, p. 19.

seemed to use flares to their advantage in the attack. It must have been with great consternation and surprise that the Viet Cong experienced their first counterattack by the heretofore harmless flareship. Immediate response capability provided by an aircraft that can drop an almost unlimited number of flares and then follow up those drops with ordnance delivery is a major contribution to night air support in Vietnam. The VC can never again be certain that flares are not a prelude to immediate attack from the air.

While the major contribution to night air operations in Vietnam has been by Army, Air Force, and Marine Corps aircraft, the U. S. Navy also provided limited numbers of aircraft for this purpose. As previously mentioned, the AD-5's (A-1E) were employed in 1962 and 1963 in a night air defense role. Additional Navy participation was indicated late in 1964. At 2305 on 15 December, the radar cite at Da Nang reported high speed boats operating in the area. A VNAF C-47 dropped forty-three flares escorted by two A-1H's. At 2355, Navy aircraft from Seventh Fleet aircraft carriers arrived in the area. They performed illumination and search operations but found only some fishing boats.[13] If the general military activity in Vietnam continues to escalate during 1965, it is anticipated that naval air participation by Seventh Fleet aircraft may increase significantly.

The second tool of importance to night air operations is the variety of illumination devices used by ground and air forces in Vietnam.

As indicated in Chapter III, the primary means of providing battlefield illumination to counterinsurgent forces in South Vietnam has been the aircraft dropped parachute flare. From 11 March 1964 through

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[13] *Ibid.*, MILREP Week of 12 Dec 64, p. 16.

31 January 1965, 55,715 parachute flares were dropped from C-47 and C-123 aircraft. This figure does not include an undetermined number dropped from Army TO-1D, OV-1, and helicopter aircraft during this same period. Although several different model parachute flares have been employed,[14] the Mark 24 is becoming the standard item in Vietnam and is currently the flare being used by Tactical Air Command in its night fighter-bomber training program. This flare may be dispensed by hand from flareships or from special flare racks carried on bomb stations under the wings of fighter aircraft.

Other devices have been used effectively under circumstances requiring immediate illumination. Major Gorvad, in his questionnaire, alluded to the required use of mortar fired illuminating rounds when air dropped flares were not immediately available.[15] Major Pulsipher also mentioned use of artillery flares on ten occasions and 60mm mortar illuminating rounds and hand held flares on others.[16] The MACV MILREPS contain numerous references throughout 1964 to use of ground fired illumination. The universal complaint, however, is the sacrifice of firepower inherent in using artillery or mortars for illumination missions. In consideration of the relatively short burning times of mortar and artillery illuminating shells and consequently the large

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[14] The three models of flares used in Vietnam are the Mark 6, the Mark 24, and the M25A1. The first of these has been the most widely used, and although not as brilliant as the Mark 24 (1,000,000 candlepower versus 2,500,000), its longer burning time (3 minutes versus 2) has been a significant advantage.

[15] Questionnaire, Maj. Peter L. Gorvad, Inf., USA, USACGSC Student, 19 Nov 64.

[16] Questionnaire, Maj. Elwin D. Pulsipher, Inf., USA, USACGSC Student, 19 Nov 64.

number of rounds which must be fired to maintain continuous illumination, the logistics problem becomes significant also. We may conclude that in a counterinsurgency environment, with its attendant scattering of forces, the air dropped flare will continue to be the most effective overall illuminating device. We must also conclude, however, that each unit from battalion down to squad and each village or outpost should have a limited organic capability to provide its own illumination until a flareship can assume the mission. This conclusion is supported by MACV in lessons learned from the VC attack on Nam Dong Special Forces Camp on 6 July 1964.

> THE CAMP MUST PRACTICE ILLUMINATING THE SURROUNDING AREA EITHER BY ELECTRIC LIGHTS OR ARTIFICIAL ILLUMINATION AT IRREGULAR INTERVALS DURING HOURS OF DARKNESS. BURNING BUILDINGS, NEAR POSSIBLE AVENUES OF APPROACH DURING AN ATTACK, IGNITED BY PREPLACED CHARGES OR ELECTRICALLY DETONATED CAN PROVIDE EXCELLENT ILLUMINATION.[17]

"It seems apparent that battlefield illumination has tremendous tactical possibilities which have not been exploited."[18]

The third tool which plays a vital part in night air operations concerns communications equipment. In 1962 and 1963, the most significant ground support problem affecting night air operations in Vietnam was the lack of compatible radios. Again, this is a subject worthy of exhaustive analysis but beyond the scope of this paper. In brief, the problems began in the initial stages of development of the hamlet warning system. The most common radio in use was the AN/PRC-10 --a relatively small, often unreliable, and short ranged means of

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[17]U. S. Military Assistance Command, Vietnam, op. cit., MILREP Week of 4 Jul 64, pp. 27-28.

[18]H. Richard Blackwell, "Battlefield Illumination by Visible Light," Project MICHIGAN (Ann Arbor, Michigan: Univeristy of Michigan, 25 Jan 55), p. 123.

communication. Special antennae had to be designed and built to insure minimum satisfactory operation between villages and sector headquarters.[19] These radios also presented problems when used in Forward Air Control (FAC) aircraft due to their sensitivity to vibration. A conservative estimate of airborne radio failure on combat missions during 1962 would be 25 per cent.

The language barrier in concert with general unreliability of airborne radio equipment made successful completion of a Vietnamese directed interdiction or close air support mission more a matter of luck than of skill. The Director of Army Aviation in Vietnam during 1962, in reporting on operations in general, made repeated references to the problem of unreliable and incompatible radios and their effect on air operations.[20] A Rand Ad Hoc Group studying the problems of counterinsurgency and air power concluded that there was a definite need for "coded target indicating devices for use (instead of voice communications) between Forward Air Controllers on the ground and strike aircraft to get around language barriers and other problems."[21]

A project to install the reliable AN/ARC-44 radio in all aircraft was initiated during the summer of 1962. However, it took almost

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[19] U. S. Army MAAG, II VN Corps Detachment, Pleiku, Vietnam, "Village Early Warning System, Memorandum" (Pleiku, Vietnam: U. S. Army MAAG, II VN Corps Detachment, 2 Oct 62), p. 2.

[20] Director of Army Aviation, "U. S. Army Aviation Operations in South Vietnam" (Washington, D. C.: Office of the Deputy Chief of Staff for Military Operations, Department of the Army, 1 Oct 62), pp. 18-19.

[21] H. Speier et al, Counter-Insurgency and Air Power: Report of a Rand Ad Hoc Group, Memorandum RM-3203-PR (Santa Monica, California: The Rand Corporation, Jun 62), p. 36.

two years before these radios were in general use. The first comprehensive report on this project appeared in the MACV MILREP for the week of 2 May 1964 and indicated that the majority of aircraft then in Vietnam were now equipped with the new radio and that aircraft scheduled for assignment to Vietnam would have the AN/ARC-44 radio installed prior to arrival.[22]

Navigational aid equipment presented still other problems for night air operations in Vietnam. There has been a dearth of aids to navigation in Vietnam from the beginning, due, in part, to the fact that very little if any night flying was conducted prior to arrival of United States air units. With the advent of increasing air activity, and particularly night air activity, the need for new and modern "NAVAID" equipment became critical. The three radar sites at Saigon, Pleiku, and Da Nang provide primary navigational assistance, and the remainder is provided by a few Low Frequency Range stations and a limited number of Visual Omni Radios (VOR). Ground Controlled Approach (GCA) and Tactical Air Navigation (TACAN) facilities have been installed at most major airfields only during the past twelve months. The GCA and TACAN facilities were installed at Bien Hoa on 15 August 1964.[23] It is assumed that this equipment was required as significant numbers of jet aircraft were deployed to Vietnam; aircraft which, in most cases, are equipped only with TACAN. It is important to realize that not only in Vietnam but in many of the underdeveloped countries of the world in which we may be called upon to fight a counterinsurgency war, navigational aids may be extremely austere or non-existent. Effective

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[22] U. S. Military Assistance Command, Vietnam, op. cit., MILREP Week of 2 May 64, pp. 6-7.

[23] Ibid., MILREP Week of 8 Aug 64, p. 51.

counterinsurgency night air operations of both defensive and offensive nature require means whereby a pilot can accurately locate his target. The "flaming arrow" is an effective aid in locating a defensive target after a general vector has been provided by ground radar, but offensive operations require much more accurate navigation. One method will be discussed later in this chapter.

Aircraft, illumination, and electronic devices have been basic tools of the trade for night air operations in Vietnam. While these tools have been used with relative effectiveness, recent technological developments in all of these fields, plus recognition and exploitation of tactics, techniques, and equipment used in other wars, point to many additional ways in which the airplane, illumination devices, surveillance devices, and communications equipment may be used to advantage for night air operations in the future.

Tests and Experiments

Growing recognition of night as the battlefield environment for counterinsurgency operations has brought about several equipment tests in Vietnam, oriented on improving night air operations. One of these was a test of feasibility of Tactical Area Positioning System (TAPS) equipment for use in counterinsurgency. The TAPS, originally known as the Decca Navigation System, was tested in B-26, C-123, and H-21 aircraft from 20 December 1962 to 20 July 1963.[24] Its purpose was to provide pilots with a graphic presentation of their exact position over the ground. Implications for night operations are obvious,

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[24] U. S. Air Force 2d Air Division Final Report, "Operational Test and Evaluation of the Tactical Area Positioning System in the Republic of Vietnam," PACAF Test Directive No. 63-1 (Saigon, Vietnam: U. S. Air Force 2d Air Division, 20 Aug 63), p. ii.

however, navigational accuracies of plus or minus 10 meters at distances of 40 nautical miles, and plus or minus 600 meters at 240 nautical miles were attainable, with necessary reliability, only during daylight hours.[25] "Night effect" on propogation of low frequency radio waves rendered the equipment unreliable at night.[26]

The Combat Development and Test Center in Vietnam experimented with a chemiluminescent compound called TIARA (Target Illumination and Rescue Aid) which emits a strong glow when exposed to air. Although the test was primarily to examine uses of TIARA devices for marking rifle sights and for hand grenade or rifle grenade spotting rounds, evaluators were more enthusiastic about possibilities of using the grenade "as a reference point to direct fire,. . . and as a target guide for support aircraft."[27] Several strategically located TIARA grenades or artillery shells detonated on the perimeter of an outpost or village could provide target identification necessary to permit strike aircraft to expend ordnance on enemy forces outside the post perimeter when flare illumination was not immediately available.

Additional experiments have been and are being conducted in Vietnam in the field of infrared photography and passive and active infrared surveillance devices with encouraging results.[28]

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[25]U. S. Army Concept Team in Vietnam Final Report, "Evaluation of Tactical Area Positioning System (TAPS) in Army Helicopters" (Saigon, Vietnam: U. S. Army Concept Team in Vietnam, Nov 63), p. 9.

[26]U. S. Air Force 2d Air Division Final Report, op. cit., p. 6.

[27]Combat Development and Test Center, Republic of Vietnam Armed Forces, "Operational Test of TIARA Items," A Report of CDTC-V Task Number 71D (Saigon, Vietnam: Combat Development and Test Center, Vietnam, 19 Apr 63), p. 4.

[28]U. S. Military Assistance Command, Vietnam, op. cit., MILREP, Week of 16 May 64, p. 16.

While recent tests and experiments in Vietnam are worthy of note, even more interesting are tests, experiments and "brainstorm" ideas in the field of illumination and night operations which have been conducted or proposed in other countries, in other times, and which appear to have a current application for night air warfare in a counter-insurgency environment. A cursory examination of these ideas, and their application for counterinsurgency operations, particularly in a jungle environment, may help to focus on the recent increase in interest and emphasis on night operations in general, and more specifically on night air operations.

The ideas include a Rand Ad Hoc Group suggestion that we use "captive balloons, possibly coated by a substance making them readily detectible by radar, to provide ground troops operating in small patrols with a much needed light-weight target marking device. Other possibilities include tree-top marking by dyes, infra-red reflecting or fluorescent substances, and panel devices."[29] Also mentioned was a device which could be fired into the air above tree cover to spread a thin alluminum powder over the tree tops for radar spotting.[30]

In the realm of identification and signaling, the Signal Advisor to the 23d Tactical Area in Vietnam voiced a need for "development and supply of a parachute flare which will reach 300 meters elevation, burn in any kind of weather for at least 3 minutes and come in a variety of colors."[31]

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[29] H. Speier _et al_, _op_. _cit_., p. 36.

[30] _Ibid_., p. 104.

[31] U. S. Army MAAG, II VN Corps Detachment, Pleiku, Vietnam, op. cit.

In late 1962, the U. S. Marine Corps suggested using chemiluminescent compounds in the form of powders or sprays for target marking. They also considered use of LASER light beams to inflict burns or blindness on an enemy.[32] The Rand Ad Hoc Group also discussed use of high intensity light to blind or burn guerrillas to facilitate later identification and separation from the friendly populace.[33]

A study of battlefield illumination by visible light, conducted by the University of Michigan in 1955, suggested use of an experimental light source "for continuous illumination of the battlefield from an aerial mounting platform located over friendly lines. It might be possible to mount the portable light source on a platform supported by a captive balloon, or on a platform supported by a portable tower."[34] The same study mentioned "the use of an aerial 'spotlight' [which] seems to offer considerable promise for increasing target detectability."[35]

More recently, Lockheed Aviation made a study of battlefield illumination by nuclear light which also suggests a balloon supported light.

> Even though the surface brightness is low, an incandescent nuclear light source internally powered by radioactive decay does have impressive simplicity, dependability and above all lightness. Such sources may provide 5,000 to 20,000 candles per ounce of unshielded source weight and could conceivably have wide use as balloon-supported

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[32]Marine Corps Landing Force Development Center, "Concept of Close Combat During Night Operations and Other Conditions of Low Visibility," Report of Project No. 30-61-10, Conducted by Tactics and Techniques Board (Quantico, Virginia: Marine Corps Landing Force Development Center, 31 Dec 62), p. 8.

[33]H. Speier <u>et al</u>, <u>op</u>. <u>cit</u>., p. 158.

[34]H. Richard Blackwell, <u>op</u>. <u>cit</u>., p. 105.

[35]<u>Ibid</u>., p. 79.

signals or floodlights. In comparison, a 100 watt tungsten light bulb supplies approximately 150 candle power of light.[36]

The U. S. Army Command and General Staff College, in a 1960 study of battlefield illumination, suggested using lights in helicopters and hovering drones to illuminate required areas. Also mentioned was employment of "aircraft rocket flares which can be projected ahead for immediate exploitation without aircraft having to retrace flight pattern. . ."[37] The Canadian Army, in commenting on such a rocket flare, had this to say: "It is felt that dispersal of the enemy and use of electronic surveillance and target acquisition devices on the future battlefield may make pinpoint or local illumination a greater requirement than area illumination."[38]

The Air Force Air Proving Ground proposed using an airborne searchlight on fighter-bombers for illuminating point targets after an aiming point was established.[39] Also mentioned was the M-91 Target Identification Bomb (red) which was color visible at night up to

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[36]Missile Systems Division of Lockheed Aircraft Corporation Final Report, "Battlefield Illumination Study, Nuclear Light" (Arlington Hall Station, Virginia: Reproduced by the Armed Services Technical Information Agency, n.d.), p. 41.

[37]U. S. Army Command and General Staff College, "Battlefield Illumination Study," Informal Study: Operational Doctrine for Employment of Battlefield Illumination during the period 1960-1970 (Fort Leavenworth, Kansas: U. S. Army Command and General Staff College, 10 Feb 60), p. D-31.

[38]Headquarters, U. S. CONARC Letter ATDEV-3 400.114 (C), "USCONARC-Approved Military Characteristics for Rocket System, Illuminating, Battlefield"(U), (Ft. Monroe, Virginia, 8 Sep 60), p. 6.

[39]Air Proving Ground Command, "Final Report on Fighter-Bomber Tactics and Techniques for Night Tactical Air Attack," Project No. APG/TAT/22-A-8 (Eglin, Air Force Base, Florida: Air Proving Ground Command, 1 Jul 54), p. 33.

approximately forty-five statute miles and was considered the most satisfactory target marking device used in this particular test project (1954).[40]

The U. S. Army, in a 1962 test of armed helicopter capability to deliver fires at night, concluded that "of the illumination methods (artillery, mortar, aircraft flares, and ground and air vehicle mounted searchlights) employed, the air vehicle mounted searchlight proved to be most effective."[41]

One additional device which appears to have important implications and application for night aerial warfare is the "Scotoscope" or "Starlight" scope. Mentioned briefly in the January 1965 Military Review (p. 104) and discussed in detail in a 1963 Sarnoff Research Center study, this image intensification device, which uses the natural light of the stars or other low intensity light sources, is a significant "break through" in the field of battlefield surveillance.

> Insofar as land warfare is concerned, no technical development in progress at present that we are aware of has the potential of changing the nature of future warfare so profoundly as does the scotoscope.[42]

There are limitations on use of this device for high performance aircraft; however, in a counterinsurgency environment, using relatively low performance aircraft, the scotoscope has numerous applications.

> The capability to operate, observe and use their weapons that scotoscopes give to the low flying, relatively slow V/STOL air vehicles organic to ground combat forces does not extend to

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[40] Ibid., p. 149.

[41] Headquarters, U. S. Army Armor School Letter AIBK-SKE, "Battlefield Illumination for the Delivery of Fire by Armed Helicopters," (Fort Knox, Kentucky, 16 Jun 62), p. 2.

[42] D. S. Bond and F. P. Henderson, "The Conquest of Darkness," A Study of Scotoscopes and Their Impact on Warfare (Princeton, New Jersey: Advanced Military Systems Radio Corporation of America, David Sarnoff Research Center, Jul 63), p. 4.

> conventional high performance tactical aircraft used in support of ground forces. The present range of scotoscopes is inadequate for the normal operating speeds and altitudes of these aircraft. However, scotoscopes may be of considerable assistance to them in take-off, landing and taxi operations when operating from forward landing fields under blackout conditions.[43]

With the anticipated development of a "pure" counterinsurgency aircraft with V/STOL sharacteristics, the scotoscope may well change the entire concept of night air operations in a counterinsurgency environment.

We have mentioned just a few of an almost endless list of unique, sometimes practical, and sometimes impractical, devices which, in the future, may be seen on night battlefields in both conventional and unconventional warfare. Perhaps the most impressive and intriguing by-product of warfare of any kind is the improvement and development of military equipment, born of need, which the ingenuity of man will foster.

Tactics and Techniques

Although resourcefulness of military man is readily apparent in development of innovations in military hardware, in the field of tactics and techniques this adroitness is even more evident. Every soldier and airman, regardless of rank, is a would be tactician. Suggestions, recommendations, and proposals in the field of tactics will never be in short supply. Vietnam has been a particularly fertile ground for development of new tactics and techniques.

The majority of tactics and techniques used in Vietnam for employment of air power at night were not especially new innovations or inspirations of military genius; rather, they were tactics or modifications of tactics used in World War II, in Korea, or in counterinsurgency operations conducted during the past fifteen years. That

[43] Ibid., p. 54.

we did not immediately employ the latest tactics upon entry into Vietnam is understandable. There was the inevitable relearning process which accompanies most military operations conducted after a period of peace. A Joint Air-Ground Operations Conference conducted in Korea, immediately following the Armistice in 1953, observed that "many of the lessons learned in World War II had to be relearned in Korea. On the other hand, many of the procedures, tactics and techniques practiced in Korea may not have application in future operations."[44] This relearning of tactics and techniques has been characteristic of our effort in Vietnam, and we have eliminated and innovated to meet requirements of that particular environment.

To provide a comparison of night air tactics in the Vietnam of early 1965 and night air tactics from other wars, we first list the most commonly used tactics as they developed in Vietnam. This will be followed by a general discussion of tactics and techniques used during similar or related operations in previous armed conflict.

The initial "tactic" for use of flare aircraft was ground alert status; aircraft "scrambled" when a request was forwarded through the air request net.

This tactic naturally evolved into airborne alert status with resultant decrease in reaction time. Additional aircraft were maintained on ground alert for backup purposes.

All-night air cover was the next step and involved relays of flareships replacing the airborne alert to provide continuous response capability throughout the hours of darkness.

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[44]Col. William J. Yates, USAF, "Report on Joing Air-Ground Operations Conference" (Seoul, Korea: Headquarters, Fifth Air Force, 8-22 Aug 53), p. 23.

The next step was combined flareship-strike aircraft airborne alert. Fighter-bomber and flareship "teams" provided a minimum-response-time illumination and firepower capability.

The final flareship tactic involved arming the airplane to provide an integrated flare-strike capability in one aircraft.

During this evolutionary period, the tactical missions of flareships included adjustment of artillery fire as well as coordination and control of strike aircraft fires.

Strike aircraft tactics developed in much the same manner. Initially aircraft stood ground alert and "scrambled" only on specific request.

This tactic was followed by air alert (combat air patrol) particularly in the III and IV Corps Tactical Zones where night activity has been most intense. In both cases, strikes were conducted under illumination provided by flareships.

A refinement of this tactic was the coordinated attack using artillery illumination in conjunction with artillery fires and fighter-bomber strikes.

A three-way operation followed, with artillery, flareship, and fighter-bomber colaborating in mutually supported strikes or defensive operations.

During this period, strike aircraft were occasionally employed in support of outposts under attack, without benefit of flareship illumination. These strikes were normally made only on those villages or posts equipped with the "flaming arrow." In some instances, when the "arrow" was not available, outposts used tracer ammunition to show direction to the enemy.[45]

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[45] Aircraft Losses Operations Analysis Working Group, op. cit., p. D-4-2.

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One of the more recent tactics (mid-1964) has been the use of armed helicopters in conjunction with flareships, or in a "solo" role dropping their own flares and then expending ordnance. This tactic has been used both offensively and defensively with impressive results.

All of the preceeding tactics (with the possible exception of the armed helicopter operation) have been used previously in unlimited, limited, and/or counterinsurgency warfare. While precise execution of these tactics may have changed to accomodate new aircraft or ordnance capabilities, the basic tactics are unchanging. The major change which can be recognized in employment of air power at night is new emphasis on its use.

Examination of tactics used by participants in night aerial warfare of the past leads to an initial conclusion that success normally involves a cooperative effort on the part of ground and air forces. Col. R. Laure of the French Army, a veteran of both the Algerian and Indo-Chinese conflicts, asserts that "counterguerrilla war is a combined Air-Army problem requiring a lot of imagination and cooperation--in other words, a human problem rather than a technical problem. This is my opinion after spending four years in guerrilla warfare and three others in Southeast Asia, and I think I am an air-minded Army officer."[46]

In July 1963, The Rand Corporation conducted a series of symposiums on use of air power in counterinsurgency and unconventional warfare. Participants in the Malayan Emergency, the Philippine Huk Campaign, the Algerian War, Chindit Operations in Burma, Allied Resistance to the Japanese on Luzon, and Unconventional Warfare in the

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[46] A. H. Peterson, G. C. Reinhardt, and E. E. Conger, "Symposium on the Role of Airpower in Counterinsurgency and Unconventional Warfare: The Algerian War," Memorandum RM-3653-PR (Santa Monica, California: The Rand Corporation, Jul 63), p. 63.

Mediterranean Theatre were brought together to discuss their experiences and to attempt to apply their knowledge to present and future counterinsurgent air operations. Before citing some of the tactics and techniques which these "experts" expound, the author gives recognition to the fact that no two military operations will ever be precisely the same. Internal and external forces, limitations, and technological developments will always be different. Therefore, these experiences are presented only to provide a general background for development of the theses that night air operations are evolving as doctrine for counterinsurgent warfare and that this evolution is rooted in past conflicts as well as in the present Vietnamese war.

In the symposium on the Malayan Emergency, Air Commodore P. E. Warcup, C.B.E. (Royal Air Force) said:

> I think all of us will agree that for offensive air operations to be successful, certain conditions must be fulfilled. . . . these are an identifiable target, its exact geographic location, and an attacking force capable of accurate navigation to the target and carrying a weapon suited to the target.[47]

Unfortunately, most of these conditions are noticeably not an inherent part of the night air environment in Vietnam. Commodore Warcup went on to discuss several methods of satisfying his prerequisites by using level-bomber aircraft.

> Two bombing methods were used. The first, a form of target marking by Army reconnaissance planes with the bombers aiming at the target marker, was not frightfully accurate. Eventually a radar technique was developed that was extremely accurate and was independent of night and weather. With the radar technique, the aircraft would be directed to a point in space and the pilot told when to release his bombs . . . Sometimes we bombed merely to flush CT's out of an area . . . other times we scattered bombs around the place to keep the CT's awake and to make life generally difficult for them.[48]

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[47] A. H. Peterson, G. C. Reinhardt, and E. E. Conger, "Symposium on the Role of Airpower in Counterinsurgency and Unconventional Warfare: The Malayan Emergency," Memorandum RM-3651-PR (Santa Monica, California: The Rand Corporation, Jul 63), p. 48.

[48] Ibid., p. 49.

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A tactic mentioned by Air Commodore A. D. J. Garrison, O.B.E. (Royal Australian Air Force) for use of level bombers has implications for night attacks on many areas in Vietnam.

> Bombing was done on a timed run, a given distance and direction from some fixed point that could be clearly identified. There were various means of finding the target. In lieu of a fixed point on the ground that you could pick up visually or by radar, a searchlight put up by the troops or a radio beacon carried by them would suffice; any way to get a pinpoint some distance back from the target. Given that, you could bomb extremely accurately. . . . We also used balloons put up out of the jungle by the ground forces.
> . . . .
> Operations were conducted 24 hours a day as required.[49]

There are also records of effective results being achieved by B-29 level bombing in close support of ground forces during the Korean War.[50] Since that time there has been little, if any, emphasis placed on the use of the level-bomber in close support of ground forces, particularly in counterinsurgency warfare. A tactic which might well evolve out of the aforementioned procedure is use of air dropped flares to light an Initial Point (IP) for a bombing run. The bomb run itself would then be conducted on the actual target several miles away without illumination. This tactic might catch the VC out from under protection, looking at the deceptive flare burning in the distance. Squadron Leader J. C. Hartley, a Royal Australian Air Force navigator in Malaya, described a technique similar to that just mentioned.

> For night bombing the Army very conveniently set up a brace of searchlights pointing vertically in . . . two positions for us. . . . We have run as much as 20,000 yards from known points, though we tried to keep them down to about 6000. . . . The beauty of this

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[49] *Ibid.*, pp. 60-61.

[50] S. H. Turkel, "Close Air Support, Volume II, Background and Evaluation of Developments and Operations" (Culver City, California: Aerospace Group, Aeronautical Systems Division, Hughes Aircraft Company, Jul 62), p. 84.

> type of run, of course, was the fact that you could drop blind. . . . Today this technique would be greatly simplified with the use of Doppler, and would be the easiest thing in the world to do.[51]

Squadron Leader Hartley also cited several "new" reasons for using air dropped flares.

> We did quite a bit of flare-dropping for two reasons: One, to keep the Communists awake, keep them moving, keep them upset; and second, to allow Gurkhas to extricate themselves from untenable positions at night. . . . We have sat there for hours dropping flares to light the area for the Gurkhas to execute what they called a 'planned withdrawal.'[52]

In the Philippines, during World War II, the sound alone of an aircraft was adequate to deter enemy activity. "By keeping a plane over Clark Field and another over the Manila Field area, anybody showing a light would be hopped on, and it kept them in their foxholes."[53] In Vietnam, the sound of aircraft must also cause the VC to restrict their movement to some degree.

Lt. Col. M. W. Sutcliffe (British Army) commented on the psychological aspects of night bombing.

> There was quite a little night bombing with psychological impact. There would be, maybe one aircraft coming over each half hour, perhaps for as long as a week. This certainly had a deterring effect, although in the long term, primarily a psychological effect on morale.[54]

Squadron Leader A. J. Fookes (Royal Australian Air Force) made reference to several additional methods for using night air operations as a psychological weapon.

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[51] A. H. Peterson, G. C. Reinhardt, and E. E. Conger, op. cit., p. 64.

[52] Ibid., p. 65.

[53] Naval Air Intelligence Group (OP-16-V), "Interview of Comdr. Turner F. Caldwell, Jr., USN," C.O. Night Air Group 41, U.S.S. Independence (Washington, D. C.: Division of Naval Intelligence, Office of the Chief of Naval Operations, Navy Department, 23 Mar 45), p. 2.

[54] A. H. Peterson, G. C. Reinhardt, and E. E. Conger, op. cit., p. 69.

> Sometimes when CT's were in a general area, you had a tape with just noise, squeals and bangs. The aircraft flew up and down at night to keep them awake. . . . A point on psychological warfare that hasn't been mentioned before; quite often on a supply drop we would be diverted a few miles to drop some rifle or machine gun simulators, delightful little things, just a string of .30 caliber or .303 rifle cartridges with some means of exploding them. They usually had a delay of five to eight hours. You just threw them indiscriminantly into the jungle. Sometime during the night they started going off. Some of them sounded like machine guns; others would be single shots. This was just to keep the terrorists awake. I believe it would still be a good idea.[55]

There is no record of this tactic being used in Vietnam, however, it would appear to have merit particularly in the more remote and inaccessible areas in which the Viet Cong operate.

The symposium on the Algerian War brought out several additional points of interest relevant to night air operations and their value in counterinsurgency. Col. J. Mitterand, (French Air Force) referred to one incident where "the commander of Touggourt also requested aircraft with flares for night surveillance. The area was light [sic] all night by flares, not to continue the fire action, but to oblige the band to stop and hide in the bushes."[56]

Lt. Gen. Y. P. Ezanno (French Air Force) made several interesting comments on the use of ordnance and ordnance delivery means by air.

> We used, on many occasions, one to three-hour delay fuzing against rebel regroupment areas. We would bomb them before nightfall and hope that the enemy would come in during the night and be blown up. That had a morale effect, anyway.[57]

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[55]Ibid., pp. 69-70.

[56]A. H. Peterson, G. C. Reinhardt, and E. E. Conger, "Symposium on the Role of Airpower in Counterinsurgency and Unconventional Warfare: The Algerian War," Memorandum RM-3653-PR (Santa Monica, California: The Rand Corporation, Jul 63), p. 70. (This action occurred in Oct 59.)

[57]Ibid., p. 41.

This tactic was and is being used in Vietnam, however, it is very difficult to determine specific results. It undoubtedly makes the VC wary of handling unexploded ordnance.

General Ezanno discussed one tactic which appears to have considerable merit for use in Vietnam, particularly at night, and which points to possible modification of our present tactics and equipment.

> With a chopper, you take the strong point as the center of a large orbit. You keep flying around it at an altitude of about fifteen hundred feet. . . . The answer is to stay high and shoot far. Then you have it. That you can't do with an aircraft. This orbital firing was awfully deadly. In many instances, it was used very successfully without any losses. . . . Also the fallacious tendency was to try to equip choppers with forward armament instead of side armament--we changed that because our experience proved that was no good. . . . When do you see your enemy ahead of you in this type of warfare? You see him from above or sideways--that is why we discarded the axial armament. You must have lateral armament. That is why the axial armament in a helicopter is no good. The same applied to rockets. We tried all that.[58]

The preceeding comments and anecdotes may have value if we apply them intelligently to the situation in Vietnam. One thing is evident; there are as many ways to accomplish a mission as there are people who have the mission of accomplishment. There should be no effort spared however, in critical study of recorded experiences of those who have been down this road before, and application of the knowledge gained to appropriate problems which we face today.

Reducing Vulnerability

In Chapter II, we briefly discussed the problem of antiaircraft fire and vulnerability of aircraft to ground fire in a counterinsurgency air operations. It was suggested that by increasing night air operations we could partially solve this problem.

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[58] Ibid., p. 43.

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Statistics compiled by the Aircraft Losses Operations Analysis Working Group in Vietnam strongly support this suggestion. This group concluded that "given the present VC AA materiel, the hit rates experienced at night should be considerably lower than in daylight due to the difficulty of visual target acquisition and tracking in the dark. . . . The chance of being hit when fired on at night is markedly less than that in the daytime."[59] The following figures support this statement. There were only two aircraft types for which detailed records of ground fire incidents and hits were available--the B-26 and the U-10B. During the three month period, January through March 1964, B-26 pilots detected ground fire on twenty-four occasions during the day and on twenty-seven at night. Of these incidents, actual hits were scored on six aircraft during the day and on one at night. During the period December 1963 through May 1964, U-10B pilots reported eighty-two ground fire incidents during the day and twenty at night, resulting in nine hits during daylight and one at night.[60]

Prior to 1963, ground fire had not been a significant threat to pilots in Vietnam. "It was not until February 1963 that RVNAF observed a rise in antiaircraft incidents and, along with this, a proportionate increase in the number of aircraft receiving hits."[61] This was the period of time when significant increases in total sorties by aircraft of all services were taking place. The increasing threat to the VC undoubtedly caused their emphasis on, and increasing capabilities in, antiaircraft fires.

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[59] Aircraft Losses Operations Analysis Working Group, <u>op. cit.</u>, p. 51.

[60] <u>Ibid.</u>, p. B-7-2.

[61] <u>Ibid.</u>, p. 71.

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The Viet Cong inventory of antiaircraft weapons has steadily improved in quantity and quality. The first American aircraft hit by ground fire was an H-21, hit on 10 January 1962 by small arms fire.[62] The first 50 calibre machine gun hit was sustained in June 1963.[63] A MACV antiaircraft study, conducted in April 1964, predicted that the VC would acquire 37mm guns as their next step in combating the increasing air power of the GVN forces.[64] Additional VC antiaircraft capability was indicated in September 1964 when "HELICOPTER CREWS OF THE 52D AVIATION BATTALION SUPPORTING A SEARCH AND DESTROY OPERATION, REPORTED RECEIVING GROUND FIRE IN THE FORM OF TWO HIGH EXPLOSIVE AND FIVE WHITE PHOSPHOROUS AIR BURSTS FROM AN UNKNOWN TYPE OF WEAPON."[65]

Incident, hit, and loss statistics and improving Viet Cong antiaircraft capabilities and potential dictate that positive measures be taken to prevent aircraft damage and loss rates from reaching prohibitive figures. Col. G. C. Reinhardt, USA, (Ret), in the Rand Symposium on Chindit Operations in Burma made the following comment:

> I believe many have not given enough thought to the impact that antiaircraft weaponry can have on operations of this kind in the future. They say, sure we can take losses--but they do not appreciate the way losses can accumulate in ground support operations. Simple arithmetic tells us we cannot sustain even a one per cent per sortie loss rate. Assuming replacements and three sorties a day, a loss ratio of only one per cent per sortie would call for replacing the entire force in approximately one month. For those

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[62] Director of Army Aviation, op. cit., p. 12.

[63] Aircraft Losses Operations Analysis Working Group, op. cit., p. 7.

[64] George M. Buck, Capt., U. S. Army, "Antiaircraft Study Viet Cong Forces Republic of Vietnam" (Saigon, Vietnam: U. S. Military Assistance Command, Vietnam, 14 Apr 64), p. 5.

[65] U. S. Military Assistance Command, Vietnam, op. cit., MILREP Week of 12 Sep 64, p. 4.

accustomed to thinking of much higher loss rates (but at a lower flying rate), this comes as a surprise. But this is what can happen with improved surface-to-air weapons.[66]

To cite a few examples of effectiveness of Viet Cong antiaircraft fire: the last week in June 1964, three air crewmen died, four were wounded and two aircraft were shot down.[67] The week of 20-26 September 1964, United States and Vietnamese air forces lost five aircraft and six received battle damage due to ground fire.[68] These are admittedly extreme weeks insofar as loss statistics are concerned, however, they demonstrate the potential hazard faced by airmen daily in their air operations in Vietnam--a hazard which we assume could be reduced appreciably by increasing night air operations.

There were only four instances found in the MACV MILREPS during the period 11 March 1964 through 31 January 1965 when aircraft were lost or received battle damage on night missions. One A-1E crash landed at Bien Hoa Airfield after receiving hits on a night close air support mission in July.[69] A C-123 flareship received hits on a flare drop mission during the first week of August,[70] and two A-1E's were shot down on a night close air support mission on 23 September 1964.[71]

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[66]A. H. Peterson, G. C. Reinhardt, and E. E. Conger, "Symposium on the Role of Airpower in Counterinsurgency and Unconventional Warfare: Chindit Operations in Burma," Memorandum RM-3654-PR (Santa Monica, California: The Rand Corporation, Jul 63), p. 43.

[67]U. S. Military Assistance Command, Vietnam, op. cit., MILREP Week of 27 Jun 64, pp. 5-6.

[68]Ibid., MILREP Week of 20 Sep 64, p. 3.

[69]Ibid., MILREP Week of 11 Jul 64, p. 15.

[70]Ibid., MILREP Week of 1 Aug 64, p. 12.

[71]Ibid., MILREP Week of 20 Sep 64, p. 14.

If we are to continue our air activity in Vietnam at the same or increasing levels during the coming months, it appears obvious that night must be more fully exploited if we are to avoid losses and damage at rates which cannot be sustained indefinitely even by the affluent "Uncle Sam."

Specific tactics and missions which can be performed with effectiveness at night and which are now bearing the brunt of VC antiaircraft fires during daylight missions, are low level strafing and napalm passes by fighter-bombers, C-123 defoliation missions, and heliborne assaults.

While more ground fire hits have been sustained on napalm passes than any other kind,[72] napalm is recognized as one of the most effective weapons employed in Vietnam, and as such should be used whenever appropriate targets are available. Emphasizing performance of napalm strikes at night would appear to offer a solution to the ground fire hit rate on this type of mission. In addition, burning napalm also provides an excellent aiming point or reference point for subsequent passes using other types of ordnance.

It is conceivable that defoliation missions, in some parts of Vietnam, could be conducted successfully at night using TIARA grenades or similar marking devices to set up initial points for low level runs. In consideration of the fact that C-123 aircraft presently receive ground fire hits on almost every defoliation mission flown, perhaps the hazards of night low level flight might well be less than those experienced due to Viet Cong gunners on the ground. By painting these aircraft as well as other combat aircraft with non-reflective paint and by installing radio altimeters and flame dampers on engine exhausts, night missions

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[72] Aircraft Losses Operations Analysis Working Group, op. cit., p. 66.

of all types may be flown with little if any interference by or loss due to ground fire.

The heliborne assault mission at night presents many problems normally not encountered during daylight operations. However, daylight heliborne missions have experienced an ever increasing number of ground fire hits and aircraft losses. The very nature of their mission makes the helicopter in an assault landing the most vulnerable of all aircraft. Again, the reduced vulnerability of aircraft at night could and should be exploited to even the score.

Final recommendations made by the Aircraft Losses Operations Analysis Working Group summarize very effectively the major problems associated with applying tools of the trade and tactics and techniques for counterinsurgency operations in the air. Although only one of the recommendations specifically makes reference to night air operations, by flying at night we may directly or indirectly solve or eliminate each of the remaining vulnerability problems, and, in addition, improve our overall capability to provide effective and decisive air support. These were the recommendations:

a. That increased emphasis be placed on the requirement for proper planning of air assault operations.
b. That joint and combined SOP's be developed for air assault operations in order to reduce planning time.
c. That single user frequencies be established and that an analysis of frequency allocation and assignment be made.
d. That detailed study be made to determine what equipment is available and required to provide necessary communications between aircraft and ground units.
e. That a concerted effort be made to encourage ARVN forces to use artillery in a fire suppression role in conjunction with air assault operations.
f. That air strikes be scheduled in conjunction with all helicopter assault landings to reduce antiaircraft fire.
g. That every effort be made to obtain improved air delivered weapons for use in Viet Nam.

h. That each mission be studied to determine the method by which aircraft can remain in the antiaircraft fire envelope for as short a time as possible while obtaining the effectiveness required.
i. That each strike aircraft carry the maximum effective load in terms of weight and or store stations available.
j. That the FAC be provided a higher performance aircraft.
k. That night air operations be increased.
l. That protective armor for aircraft be increased, provided the load carrying capability will not be severely limited or the center of gravity seriously disturbed.[73]

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[73] Ibid., p. 111.

CHAPTER V

EVOLVING DOCTRINE FOR COUNTERINSURGENCY

Night air operations are evolving as doctrine for employment of air power in counterinsurgency.

In developing this thesis, night, as an entity, was examined from a military point of view considering those factors which mitigate against and those factors which favor its use, on the ground, in the air, and in Vietnam. An analysis of the development of night air operations in Vietnam from 1962 through 1964 led to examination of equipment, tactics, techniques, and procedures used in Vietnam as well as in other counterinsurgency wars, and to an evaluation of the effects of these procedures on aircraft vulnerability.

The following conclusions may be drawn from examination and analysis of this relatively short period of military history:

(1) Night is a natural enemy to friend and to foe, on the ground or in the air.

(2) Night, when properly exploited, may be an ally to friend and to foe, on the ground or in the air.

(3) Night air operations against insurgent forces may be conducted effectively, efficiently, and with reduced vulnerability to ground fire.

(4) Through testing and experimentation, new equipment, weapons, tactics, and techniques are geing developed or adapted which will continue to improve the effectiveness of night air operations in counterinsurgency.

These conclusions do not express profound insight into the past nor

do they predict startling innovations for the future. They are simply a summary of facts which emerged from a detailed examination of night air operations in Vietnam.

Speed is not a characteristic of doctrinal development or changes in military thought. The evolution of doctrine set forth in this paper has taken place during the past twenty years. It will no doubt require additional years to fully evolve.

Although great volumes of material have been written on the subject of counterinsurgency, the treatment of night air operations in this type of warfare has been conspicuous by its absence. No single document has been found which addresses the problems of night air operations in unconventional war or which indicates specific effort toward doctrinal development in this area. In view of the favorable results achieved through use of this element of our military posture, additional emphasis on night air operations must be forthcoming.

The underlying current to historical facts which form a basis for the thesis, is this changing emphasis. While subtle and snail-like, it has had a significant influence on counterinsurgency air operations. With the passage of time, it will eventually result in the expenditure of direct effort toward exploiting the full potential of air power capabilities to contribute more effectively to counterinsurgency warfare.

Changing emphasis is the theme upon which the conclusions are based: a theme which is inherently evolutionary. The thesis is valid, based on this changing emphasis alone, therefore, we devote the final chapter to substantiation of the fact that a change in emphasis <u>is</u> occurring and that military men of all services are becoming increasingly aware of the value of night operations in counterinsurgency.

A Changing Emphasis

The most noteworthy indication that night air operations are evolving as doctrine for counterinsurgency is found in the recent emphasis which the U. S. Air Force has placed on training of Tactical Air Command pilots. This emphasis has its roots in actions and policies expressed over ten years ago.

A Joint Air-Ground Operations Conference was conducted in Korea shortly after cessation of hostilities in 1953. This conference concluded, among other things, that,

> The utilization of fighter-bomber aircraft on night close air support missions and also on night interdiction work, should be explored further. More extensive utilization would involve many apparent problems such as proper target identification, pilot experience levels, and increased terrain hazards, but it is felt as a result of past experience, that these night activities are sufficiently effective to encourage further evaluation.[1]

In 1954, the U. S. Air Force Air Proving Ground Command performed such an evaluation to determine the best tactics and techniques for employment of night tactical air power. Major General Patrick W. Timberlake, Commander of the Proving Ground, commenting on the test results, made the following statement:

> It has been determined that the use of jet fighter-bombers in the night tactical air attack role is entirely feasible under certain conditions. . . . It is believed that the whole doctrine for the employment of fighter-bombers should be re-examined, and the scope of the concept of tactical air warfare be broadened to take advantage of this unexploited potential.[2]

Later in 1954, upon completion of the test mentioned above, Air Proving Ground Command conducted a suitability test of a fighter-bomber squadron for night tactical air attack. One of the conclusions drawn from

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[1]William J. Yates, Col., USAF, "Report on Joint Air-Ground Operations Conference" (Seoul, Korea: Headquarters, Fifth Air Force, 8-22 Aug 53), p. 21.

[2]Air Proving Ground Command, "Final Report on Fighter-Bomber Tactics and Techniques for Night Tactical Air Attack," Project No. APG/TAT/22-A-8 (Eglin Air Force Base, Florida: Air Proving Ground Command, 1 Jul 54), Letter of Transmittal.

this test was that, "The application of day fighter-bombers to night operations is sufficiently effective to warrant immediate integration of this capability in the United States Air Force."[3] However, the proposal for "immediate integration" of a night air capability in the USAF was not immediately accepted. Although there were limited numbers of night missions included in the annual flying training program of Tactical Air Command, during the ensuing eight years, little, if any, emphasis was placed on improving TAC's night fighting capabilities. The nomenclature of "Fighter Day Wing" was an apt designation for TAC fighter-bomber units during this period. It is also appropriate to say that there was considerably more emphasis placed on the "fighter" aspects of training than on the close support role. Air superiority and tactical nuclear weapons delivery were, at that time, and remain today, the primary missions of TAC. However, during the past three years, additional effort has been expended to improve the capability of air to support ground operations. The U. S. Army-U. S. Air Force Close Air Support Board study, published in August 1963, concluded that there was, "a basic weakness in the field of tactics and techniques for close air support. Inadequate effort has been expended in developing ways and means of integrating air fires with ground fires in support of ground operations, including air support of night operations of small units."[4] The changing emphasis within TAC on close air support

[3]Air Proving Ground Command, "Final Report on the Operational Suitability Test of a Fighter-Bomber Squadron for Night Tactical Air Attack," Project No. APG/TAT/128-A (Eglin Air Force Base, Florida: Air Proving Ground Command, 27 Dec 54), p. 12.

[4]U. S. Army - U. S. Air Force Close Air Support Boards, "Joint Final Report U. S. Army - U. S. Air Force Close Air Support Boards" (Fort George G. Meade, Maryland: Office of the Adjutant General, Headquarters, Second United States Army, Initial Edition, Vol. IV, Aug 63), Annex H, p. 4.

in general is not pertinent to this paper, however, actions in regard to night air operations during the past few years are relevant.

Tactical Air Command initiated two programs during the spring and summer of 1963. TAC Test Order 62-66 directed the USAF Fighter Weapons School, at Nellis Air Force Base, Nevada, to conduct an evaluation of tactical fighter aircraft to conduct night air attacks.[5] This evaluation was completed in August 1963. In July 1963, TAC Operations Plan 10-63 (NIGHT OWL), directed two fighter wings to conduct weapons delivery training at night and to develop a recommended training program for all TAC fighter units. The results of these two programs were published as TAC Supplements to Air Force Training Manuals in June and July of 1964.[6] Follow-on tests were conducted at Nellis Air Force Base during the period 18 October to 12 December 1964 (phases III, IV, and V of NIGHT OWL training), and night joint fire exercises have been conducted as recently as February 1965 at Fort Hood, Texas.[7] It is readily apparent that night air operations are beginning to take a justifiably prominent position in the employment of tactical air power. Brigadier General W. D. Dunham, Deputy Commander for Direct Air Support, Twelfth

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[5]One wonders if the results of the APGC test of 1954 were considered invalid or if that test and its results were simply unknown to TAC staff officers in 1963.

[6]4520th Combat Crew Training Wing, "Report on Night Weapons Training," (Nellis Air Force Base, Nevada: 4520th Combat Crew Training Wing, Dec 64), p. 1. (TAC Supplement 2 to AFM 51-100, F-100D/F Aircrew Training Manual, 5 Jun 64, outlines night weapons delivery training requirements, and TAC Supplement 1 to AFM 55-100, Operational Procedures for F-100C/D/F Aircrews, 8 Jul 64, outlines procedural requirements for low level bombing (night), strafe (night), and MK-24 flare releases.)

[7]R. Woody, III, Lt. Col., "Tactical Demonstration Final Report," RCS TAC V12, A Report of TAC Mission Number FF-1066, Flown at Fort Hood, Texas, 11 Jan through 11 Feb 65 (Waco, Texas: Office of Deputy Commander for Direct Air Support, Headquarters, Twelfth Air Force (TAC), n. d.), p. 1.

Air Force (TAC), indicated in his leter of transmittal of the 1964 Report on Night Weapons Training that, "this should be one of our top projects for all Army units during 1965."[8]

Training of additional pilots for night operations is a priority project throughout TAC under the "NIGHT OWL" program. As a result of this training it is anticipated that many lessons will be learned which have direct application for night air operations in counterinsurgency.

In consideration of the apparent increase in emphasis and interest in night air operations within the U. S. Air Force, we could perhaps assume that a doctrine for the employment of air power at night <u>has</u> evolved, and simply leave it at that. However, the key words in the thesis are "doctrine for counterinsurgency." We have, we believe, adequately documented the peculiar problems associated with night air operations in a counterinsurgency war, and many of the lessons learned in tactical air support of Army units at Fort Hood during night maneuvers may well be applicable to the air support requirements in Vietnam or future unconventional wars. However, there would appear to be a fertile field for further testing of modern tactical fighter-bombers in close support of small units operating in jungle terrain. It is also important to emphasize the need for further testing of other types of night air support. We have perhaps become overly enamoured with "close" air support. There is always the danger of neglecting air operations which, in a counterinsurgency war, may have significantly more meaning and give greater return for our efforts. It may be appropriate to re-define "close air support" when that term is used in a counterinsurgency frame of reference. Air attacks on a Viet Cong unit deep in the jungle with

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[8] 4520th Combat Crew Training Wing, <u>op</u>. <u>cit</u>., Letter of Transmittal.

an express purpose of driving that unit into positions where government forces can engage them successfully; air strikes on Viet Cong supply dumps which necessitate their movement to other areas more vulnerable to government action; night paraflare drop missions which cause the VC to lose the advantages darkness normally give him; or night missions by "speaker" equipped aircraft offering inducements to the insurgent to surrender--is this not "close air support"? We feel, in counterinsurgency warfare, that it is; and that by employing air power at night in this way, as well as in the "normal" manner, when the situation warrants, this power will prove to be an increasingly important and worthwhile weapon in fighting unconventional wars. In support of this position, a lengthy but pertinent quote from a Rand Corporation study on counter-insurgency and air power is appropriate.

> Against insurgents air power has many roles to play in addition to direct attacks against enemy personnel and equipment. For example, it may be employed to inhibit enemy movement, to pin down enemy ground forces when they are being attacked, to protect and screen the movement of friendly forces, to divert attention from patrol activities, etc. . . . The effectiveness of tactical air operations can be enhanced if their important psychological and indirect effects are considered in advance and if the operations are conducted so as to maximize these effects. The doctrine for the tactical employment of air power may need to be broadened somewhat to encourage greater efforts to exploit psychological and indirect effects. And to supplement standard types of ordnance, the Air Force should consider undertaking the development of a variety of unconventional weapons having primary psychological rather than casualty-inflicting effects. . . . Attention should be given to the employment of air power for the following purposes:
>
> (1) To secure increased mobility for beleagured friendly forces in critical combat situations by air actions which inhibit the fire and maneuver of insurgent forces;
>
> (2) To impose critical delays upon insurgent forces and reduce their mobility;
>
> (3) To impose undesired, involuntary movements upon insurgent forces;
>
> (4) To impose increased physical strain and non-combat casualties upon insurgent forces by means of air harassment.
>
> Basically, the problem of matching the characteristics of air power more effectively with the nature of guerrilla warfare consists of finding ways to satisfy requirements for target acquisition, rapid

transmission of target intelligence, and timely and effective allocation of combat sorties to the targets. Consideration must be given to (1) the possible adaptation and extension of the uses of high performance air-weapon systems by means of appropriate modifications of equipment, and (2) the generation of new equipment and new operations techniques which are better tailored to the lower levels of violence characteristic of guerrilla warfare.[9]

While emphasis on night air operations by TAC is the key indicator which points to a changing emphasis, there are other significant indicators which demonstrate a conversion to employment of the night for counter-insurgency operations. Perhaps one of the most easily recognized of these is the gradual change in ground forces emphasis from large unit daytime actions to smaller unit operations at night.

To graphically illustrate this change and the encouraging results obtained therefrom, we have portrayed the employment of ground forces in Vietnam from 11 March 1964 through 31 January 1965 in chart form. As in Chapter III, we will indicate the purpose of each chart and comment on the apparent trends and conclusions which may be drawn. As a medium for further expansion of the concept of changing emphasis, appropriate comments which relate to the general category of the chart will be incorporated into the conclusions portion of each chart.

Before examining these statistical illustrations, we reiterate that air operations of any kind are only worthwhile as their results relate to the employment of ground forces. Air power alone may have significant effects on the course of battle, but the ultimate decision can only be reached when all facets of our military posture are brought to bear in a coordinated effort. This is the reason that an apparent

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[9]H. Speier et al, "Counter-Insurgency and Air Power: Report of a Rand Ad Hoc Group," Memorandum RM-3203-PR (Santa Monica, California: The Rand Corporation, Jun 62), pp. xi-xii.

change in doctrine for counterinsurgency ground operations has significance for counterinsurgency air operations, and this is why we include a rather detailed analysis of the changing emphasis in the employment of forces on the ground as an analysis pertinent to the conclusions of this thesis.

Chart 8

BATTALION NIGHTS IN THE FIELD

Purpose: To illustrate the weekly totals of battalion nights spent in the field.

Apparent trend: The trend is decidedly downward throughout 1964. During the first 23 weeks, the total battalion nights in the field was 9347. During the last 23 weeks, the total dropped to 7882; a decrease of almost 16 per cent.

Conclusions: While battalion operations in conventional warfare might be considered small unit operations, in counterinsurgency warfare, a battalion is a relatively large unit. In July 1963, the Army Concept Team in Vietnam stated that in counterinsurgency warfare, "battalion and regimental operations are the rule. Coordinated division and corps operations are infrequent and there is good argumentation for a great increase in company and platoon size operations."[10] The decreasing totals on this chart are significant in that, taken by themselves, they indicate an apparent reduction in emphasis on the use of larger forces in night operations (the statistics in Chart 9 tend to offset this apparent trend). This decrease in emphasis (if our assumption is correct) has important ramifications for supporting air forces. The organic communications in a battalion size force would normally be superior (if only in number) to those of an independent

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[10]Office of the Director Advanced Research Projects Agency, Field Unit, Vietnam and Joint Operation Evaluation Group, Vietnam, "Evaluation of Test Results of the Employment of OV-1 (Mohawk) Aircraft in Support of Counterinsurgency Operations" (Saigon, Vietnam: Office of the Director Advanced Research Projects Agency, Field Unit, Vietnam and Joint Operation Evaluation Group, Vietnam, 19 Jul 63), p. 1.

company or platoon, and hence the problems of coordinated air strikes, controlled from the ground, become more complex and difficult when these operations are in support of small units.

These figures are particularly important to note in relation to the figures in Charts 10, 11, and 12, which illustrate the increasing employment of smaller units.

CHART 8

BATTALION NIGHTS IN THE FIELD

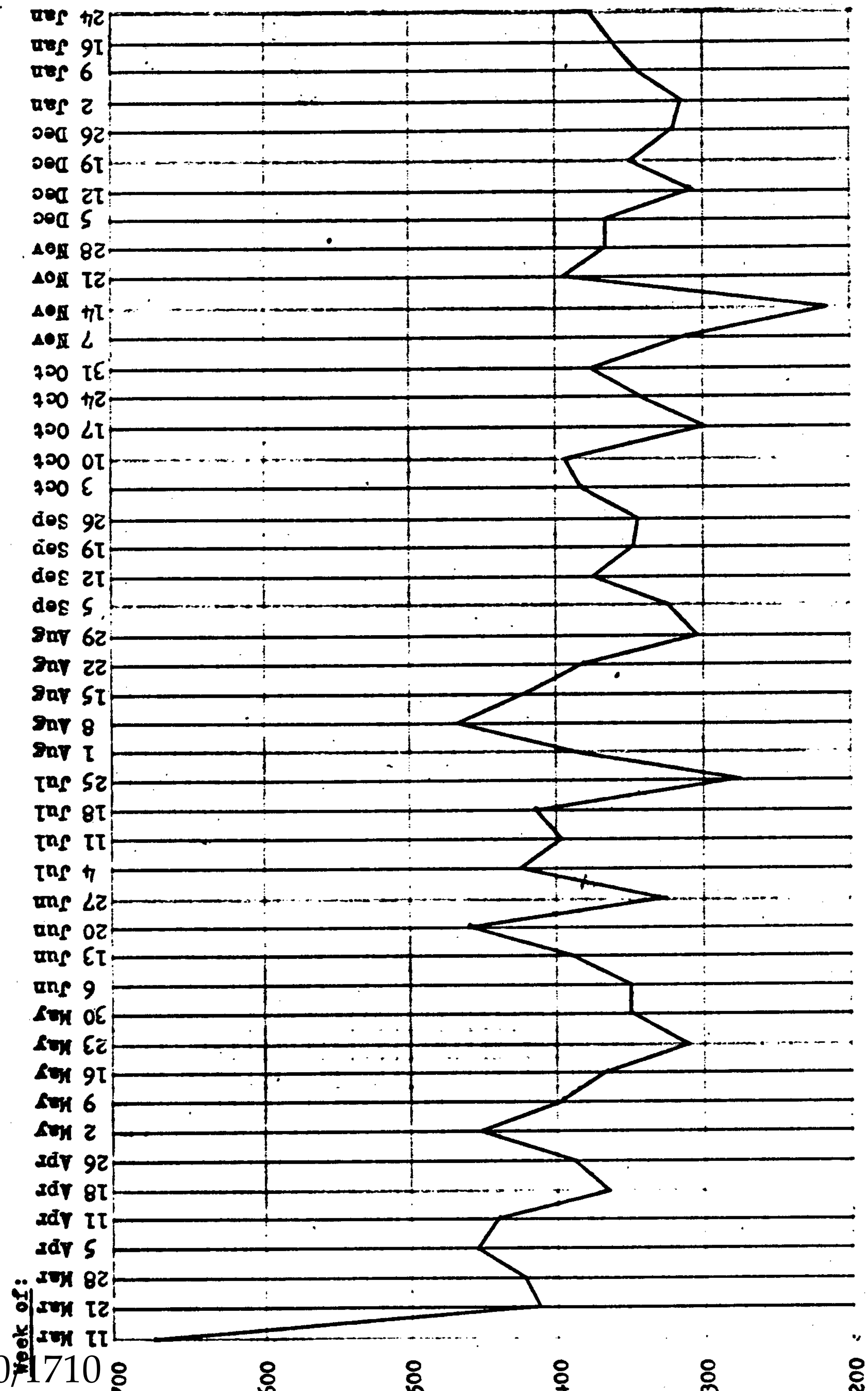

Chart 9

BATTALION OPERATIONS INITIATED PRIOR TO DAYLIGHT

Purpose: To illustrate the employment of battalion size forces in night operations.

Apparent trend: Although not immediately noticeable, the trend in operations initiated by battalions at night is upward. During the first 23 weeks there were a total of 602 operations initiated prior to daylight. During the last 23 weeks this figure increased to 679; an increase of almost 13 per cent.

Conclusions: Comparison of Charts 8 and 9 seems to indicate that while battalion nights in the field decreased appreciably, the offensive activities of those units which were employed at night was increasing by a comparatively equal amount. If we add the percentage decrease in battalion nights in the field to the percentage increase in these units' night activities, the overall increase in emphasis on night operations for battalion size units totals almost 30 per cent. Results of this emphasis, measured in actual numbers of night contacts with the Viet Cong, were not immediately apparent as indicated in the MACV MILREP for the week of 22 March 1964.

> SOME VERY ENCOURAGING RESULTS WERE OBTAINED FROM OPERATIONS STARTING IN THE EARLY MORNING HOURS, BETWEEN 0300H AND 0600H. ALTHOUGH FEW OF THESE OPERATIONS MADE CONTACT BEFORE DAYLIGHT, THE MAJORITY MAKING CONTACT, DID SO SHORTLY THEREAFTER. THIS INDICATES THAT ARVN UNITS ARE UTILIZING THE HOURS OF DARKNESS TO MOVE INTO THE OPERATIONAL AREA.[11]

However, three weeks later, continuing emphasis on night operations was resulting in significant numbers of night contacts.

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[11] U. S. Military Assistance Command, Vietnam, "Military Reports," Published Weekly, 11 Mar 64 through 31 Jan 65 (Saigon, Vietnam: U. S. Military Assistance Command, Vietnam), MILREP Week of 22 Mar 64, p. 10.

RESULTS CONTINUE TO BE ENCOURAGING WITH OVER THRITY PERCENT OF THE NIGHT OPERATIONS MAKING VC CONTACT.[12]

Night air support of this type of ground operation can be utilized effectively by providing pre-planned flare drops to facilitate night movement and by pre-planning fire support to pin down VC forces trying to evade the ARVN ground action. Planning and training are the key factors in this regard.

During 1962, one of the biggest problems encountered in providing air support to ground forces was the lack of advanced knowledge of ARVN movements. Without this knowledge, Air Force advisors were handicapped in their attempts to provide adequate air support for many of the ground operations which could have used this support to good advantage. By early 1963 the Air Force had begun to receive a limited number of requests for routine cover missions for convoys or major ground operations and was able to allocate sorties or provide ground alert aircraft as appropriate.

USMACV Directive 95-4, "Air Operations," published in September 1964, illustrates the increased efforts of air and ground forces to provide effective air support by improved coordination of planned operations.

> Senior advisors will insure pre-planning considers the use of air support for all ground operations. Plans for movement of convoys and trains, ground reconnaissance patrols, security forces and quick reaction units will include provisions for using available air support as appropriate to the requirement.[13]

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[12] Ibid., MILREP Week of 5 Apr 64, p. 12.

[13] U. S. Military Assistance Command, Vietnam, Directive No. 95-4, "Air Operations" (Saigon, Vietnam: U. S. Military Assistance Command, Vietnam, 7 Sep 64), p. 6.

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An acknowledged prerequisite to effective night air support is a complete, detailed knowledge of the planned operation, and, where possible, face to face briefings between airman and soldier.

The MACV MILREP for the week of 1 August further illustrates the emphasis given to planning for air support of ground forces.

> CHANGES IN FLARESHIP OPERATING PATTERNS AND CAPABILITIES HAVE BEEN OBSERVED THIS WEEK. THE FLARESHIP ALERT POSTURE HAS BEEN IMPROVED TO PERMIT RESPONDING TO LOWER PRIORITY REQUEST. SEVERAL GROUND OPERATIONS AND SHIP MOVEMENTS HAVE RECEIVED AIRBORNE ALERT FLARESHIP SUPPORT. IN MANY CASES FLARESHIPS RESPONDED TO GROUND REQUESTS TO SUPPORT OUTPOSTS UNDER HARASSMENT ONLY, OR WHERE AN ATTACK WAS SUSPECTED BUT NOT IN PROGRESS.[14]

Planning and training go hand in hand. Training for night operations is particularly important. U. S. Army Field Manual 20-60, Battlefield Illumination, emphasizes this point in the following statement:

> Ground units should request flare missions in order that both air and ground personnel can become familiar with the teamwork necessary to provide battlefield illumination.[15]

If we interpret the statistics of Charts 8 and 9 as illustrating a decreasing number but more carefully planned employment of battalion size forces at night, the importance of providing increased and more effective air support to these operations is paramount. This effectiveness can be enhanced to a great degree by continued emphasis on joint training.

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[14] USMACV, op. cit., MILREP Week of 1 Aug 64, p. 12.

[15] U. S. Department of the Army Field Manual 20-60, Battlefield Illumination (Washington, D. C.: U. S. Department of the Army, Oct 64), p. 25.

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CHART 9

BATTALION OPERATIONS INITIATED PRIOR TO DAYLIGHT

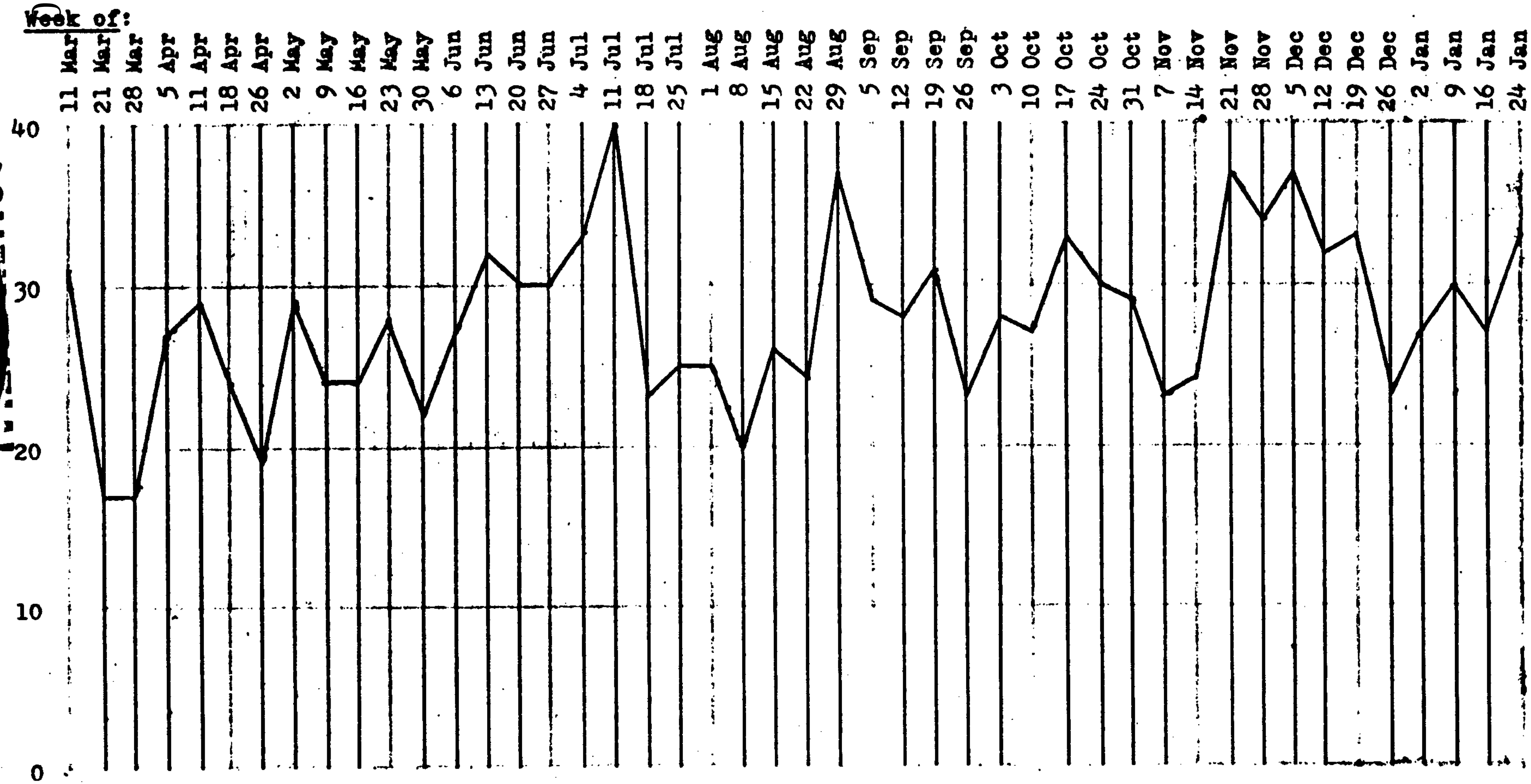

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Chart 10

TOTAL SMALL UNIT ACTIONS

Purpose: To illustrate the weekly totals of small unit (less than three rifle companies equivalent) actions. The MILREPS do not make a distinction between day and night actions, therefore, the figures in this chart represent a combination of all small unit actions without regard to the time of day during which the actions occurred.

Apparent trend: The trend illustrated in this chart does not rise as sharply as it would first appear. On 1 July 1964, the ARVN changed their reporting criteria to include units down to squad size.[16] This accounts for the sharp rise in totals during the first two weeks in July. However, notwithstanding, the trend in small unit operations is still significantly upward.

Conclusions: One conclusion which we may draw from these statistics is that the ARVN has emphasized the importance of small unit operations, and if we examine the results of this emphasis, as illustrated in Charts 11 and 12, the effectiveness of small unit operations becomes apparent.

In an attempt to apply the information contained in this chart to night air operations it was first necessary to determine an estimate of the percentage of total actions which were conducted at night. The following technique appears to be a logical method for making this determination:

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[16]USMACV, op. cit., MILREP Week of 4 Jul 64, p. 2.

Total small unit actions . . . . 529,125 (Chart 10)

Total small unit actions with day contact. . . 2,849 (Chart 11)

Total small unit actions with night contact. . 1,346 (Chart 12)

Total small unit actions with contact. 4,195

Thirty-two per cent (1,346 out of 4,195) of the contacts were made at night. We could perhaps assume that 32 percent of the actions also took place at night, however, recognizing that there is probably a greater likelihood of contact with the Viet Cong during daylight than during darkness (particularly in the employment of small units), we have arbitrarily reduced this figure to 25 per cent (this figure is in consonance with Army estimates of the percentage of operations for which night air support is required in conventional warfare, as stated in the Close Air Support Board findings of 1963).[17] If we accept this figure, then 132,281 (25 per cent of 529,125) small unit actions were conducted at night (an average of 410 per night, country-wide).

It becomes readily apparent that a capability to provide air support to operations of this magnitude requires considerable effort and planning, even if air support is only applicable and appropriate to a small percentage of these operations.

It is believed that few people fully comprehend the scope of ground activity which has and is taking place in Vietnam. To provide night air support which is truly effective in counterinsurgency warfare, commanders at all echelons must not only emphasize its use but

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[17] U. S. Army - U. S. Air Force Close Air Support Boards, op. cit., Tab S to App. 3 to Annex F

must be aware of its capabilities and limitations. An increase in emphasis on small unit actions must be accompanied by an increased effort on the part of air officers to provide the means and procedures to support this type of activity.

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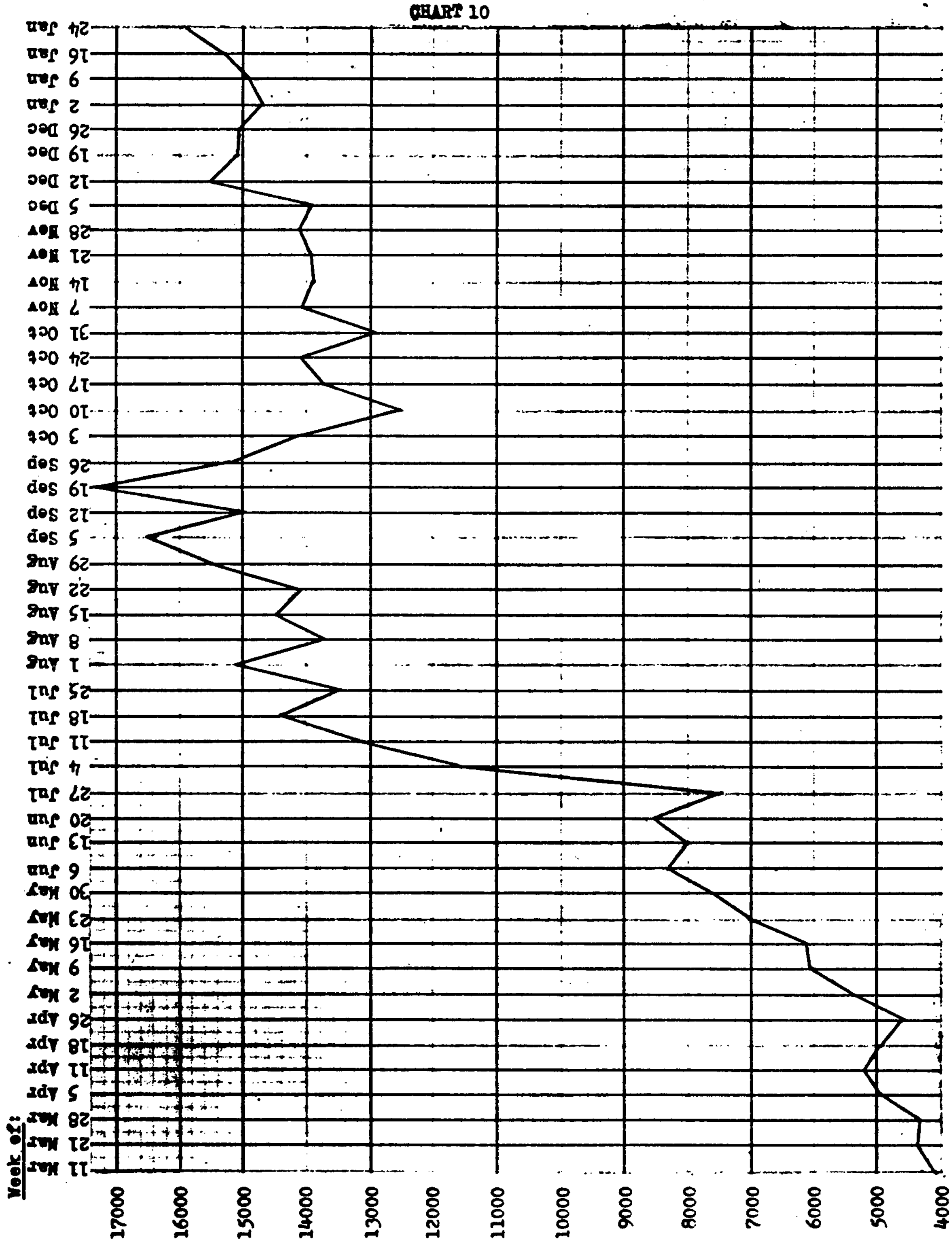
CHART 10



TOTAL SMALL UNIT ACTIONS

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Chart 11

SMALL UNIT ACTIONS WITH DAY CONTACT

Purpose: To illustrate the numbers of small unit actions in which contact was actually made with Viet Cong forces during daylight.

Apparent trend: While considerable variation is noted from week to week in the numbers of contacts, the overall trend is again decidedly upward. Total actions with contact during the first 23 weeks was 1194. During the last 23 weeks the total was 1655, an increase of almost 39 per cent.

Conclusions: Recognizing that the level of VC activity was also increasing throughout 1964, it is still significant to note the improved results of small unit actions and their apparent ability to ferret out the Viet Cong. It would appear that emphasis on small unit actions is bearing the fruit of success which its advocates have long professed.

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CHART 10

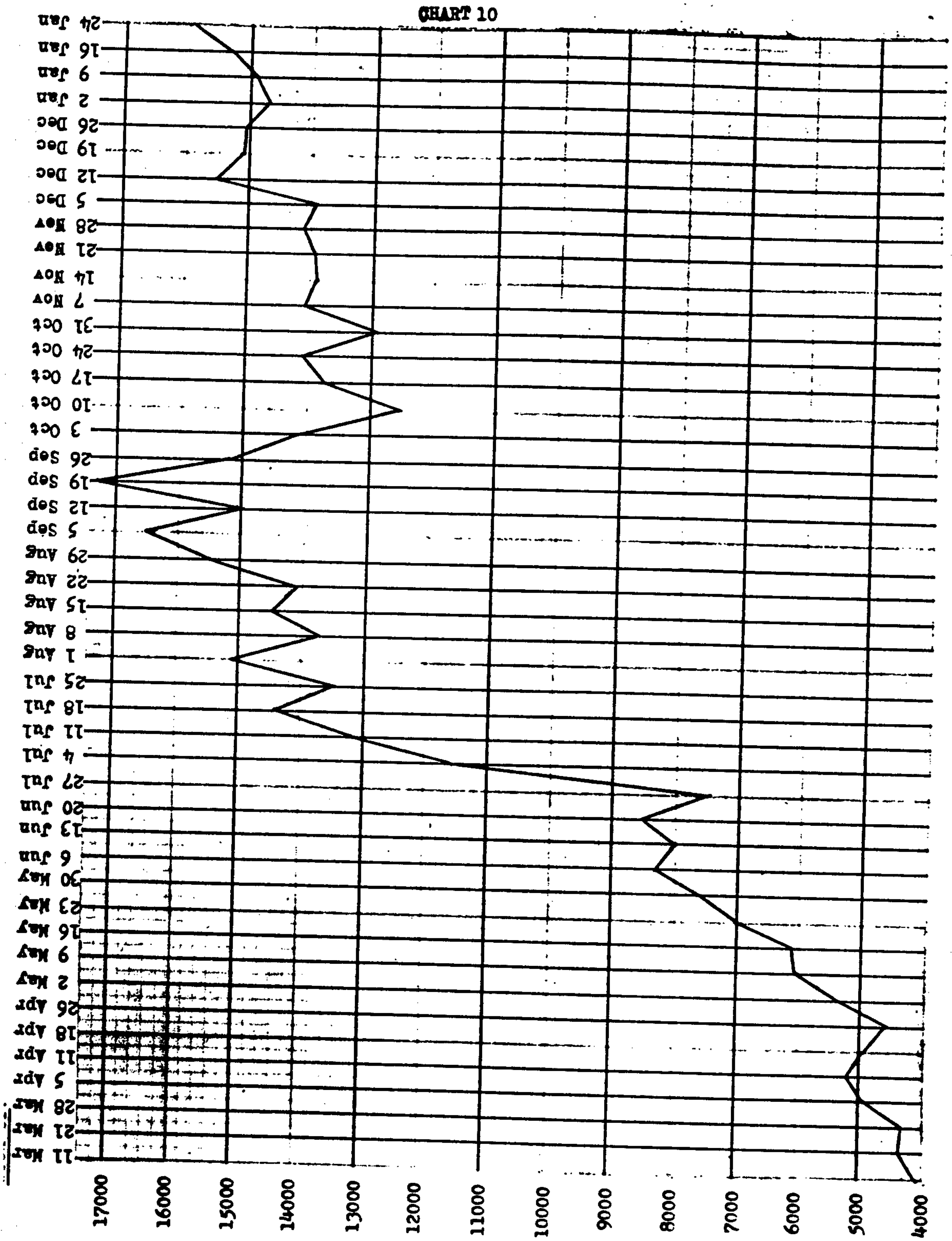

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Chart 12

SMALL UNIT ACTIONS WITH NIGHT CONTACT

Purpose: To illustrate the number of small unit actions in which contact was actually made with VC during the hours of darkness.

Apparent trend: While the trend is unmistakably downward during the first seven months of the reporting period, the trend during the last four months is even more markedly upward.

Conclusions: Several conclusions may be drawn from this chart. First, we might assume that the increasing emphasis on small unit actions by the ARVN tended to decrease the VC night movement during the first part of the year and hence the number of contacts. The assumption that VC activity was influenced by the increase in emphasis on small unit actions is supported by a comment contained in the MACV MILREP for the week of 30 May 1964.

> ARVN 2ND DIVISION UNITS IN QUANG NAM PROVINCE HAVE BEEN HAVING A CONSIDERABLE DEGREE OF SUCCESS IN SMALL UNIT NIGHT OPERATIONS. THEY HAVE CONDUCTED AMBUSHES AT NIGHT, IN THE EVENING TWILIGHT AND JUST BEFORE DAWN IN CRITICAL AREAS. . . . IN ADDITION TO CONDUCTING AMBUSHES, THEY HAVE ATTACKED THE VC AT VARYING TIMES DURING THE NIGHT REGARDLESS OF THE WEATHER AND THE TERRAIN. . . . CAPTURED DOCUMENTS REVEAL THAT THE VC BELIEVE THAT ARVN IS APPLYING COUNTER GUERRILLA TACTICS LEARNED FROM MAYLAYA.[18]

Secondly, we may conclude that as ARVN proficiency in small unit actions improved, they were able to conduct an increasing number of night operations which resulted in contact with the VC. Again, we recognize that all operations were on the rise during the latter months of 1964, however, the very sharp increase in contacts during this period can certainly be attributed, in part at least, to improved tactics and increased emphasis.

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[18] USMACV, op. cit., MILREP Week of 30 May 64, p. 11.

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The ramifications for night air operations are important in this respect also. Night close air support of small units is not always practicable, however, as we have previously redefined "close air support," there are many missions which can and have been flown which may contribute directly to the increasing success of the small unit on the ground. Of particular value is the use of air dropped flares. With proper planning and compatible communications, the air-ground team can be expected to yield truly significant results.

While we have indicated that the emphasis on small unit operations was promulgated by ARVN, "A POINT OF INTEREST IS THAT, OF THE TOTAL SMALL UNIT NIGHT OPERATIONS WHICH PRODUCED VC CONTACT, 92 PERCENT WERE CONDUCTED BY THE PARA-MILITARY (SDC, CG, CIDG)."[19] This emphasis by paramilitary forces continued throughout 1964.

> COMPARISON OF OFFENSIVE OPERATIONS CONDUCTED BY CIDG FORCES DURING MONTH OF SEP INDICATED A TEN PER CENT INCREASE IN CIDG INITIATED AMBUSHES (2883) AND A FIFTY PER CENT INCREASE IN NIGHT OPERATIONS (2959).[20]

If we are to continue improving the results of this type of operation, and if this employment of ground forces remains Army doctrine for counterinsurgency, it is incumbent on supporting air forces to provide that measure of air power appropriate to the need. General Blumentritt went so far as to state that, "the best thing to do is to build up special night air forces trained specifically for

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[19] Ibid., MILREP Week of 5 Apr 64, p. 12.

[20] Ibid., MILREP Week of 3 Oct 64, p. 23.

cooperation with ground forces."[21] Air Force doctrine provides a capability which falls somewhat short of this ideal, however, increased concentration on training for night air operations should provide forces which are fully capable of effective air operations, day or night, with ground forces of any size and composition.

The problems of night air support of small units in jungle terrain are many and difficult, however, the capability and potential is there if we but expend the effort to overcome the obstacles.

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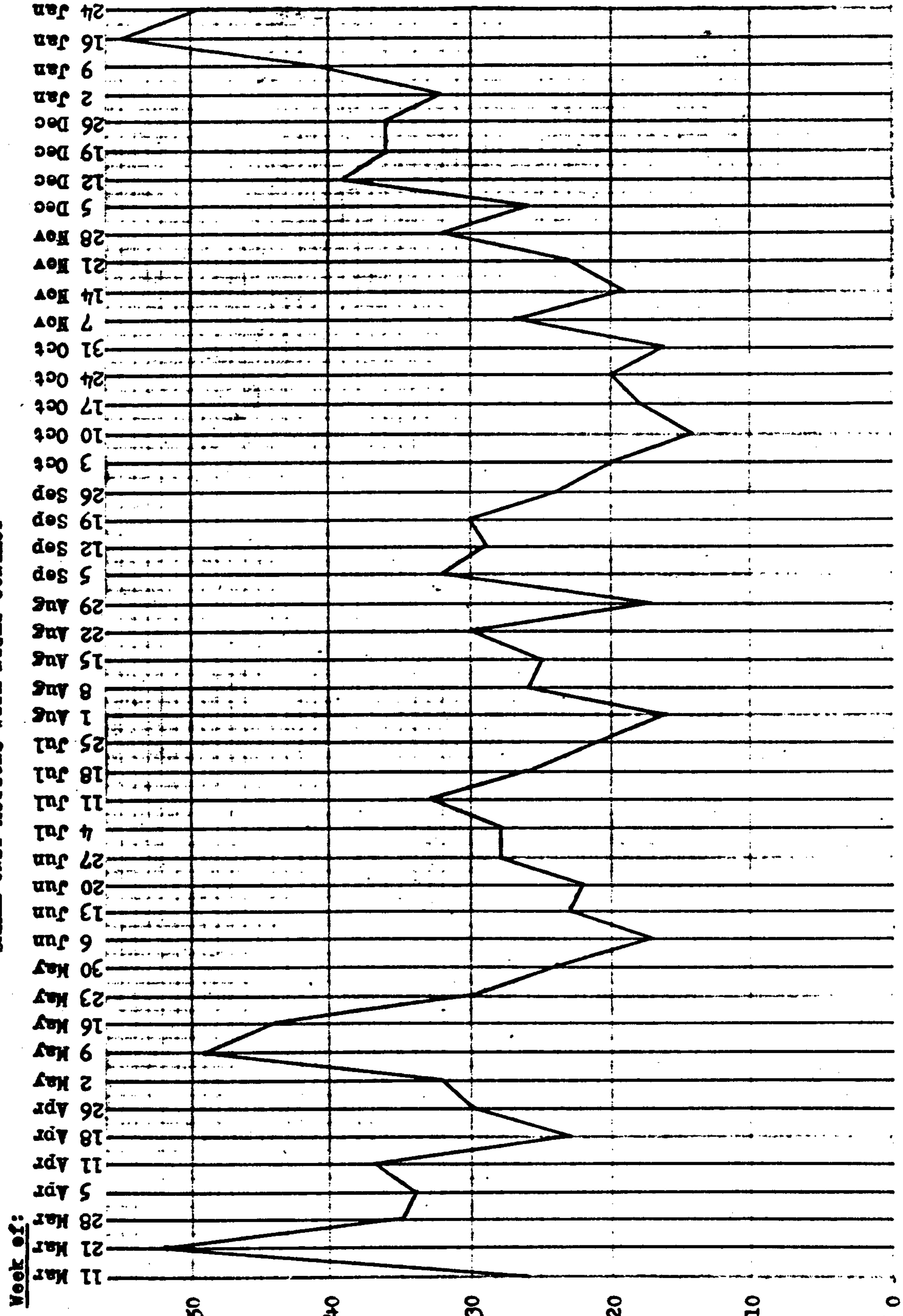
[21]Guenther Blumentritt, General der Infanterie a.D., "Operations in Darkness and Smoke," Manuscript No. B-683, Trans. A. Schroeder, Ed. H. Hertman, Originally prepared by Historical Division European Command, Foreign Military Studies Branch (Washington, D. C.: Office of the Chief of Military History, Department of the Army, 1952), p. 16.

CHART 12

SMALL UNIT ACTIONS WITH NIGHT CONTACT



COIN in the Future

Evolution implies continuance. Evolving military doctrine is perhaps one of the best examples of this never-ending change. In the case of specific doctrine for counterinsurgency, the history which pertains to its evolution does not cease to be made, with the doctrine then emerging as a finite set of rules. What has transpired serves only as a base upon which we may build near range predictions as to what will transpire in the future. Even as we make these predictions, current developments may reshape our estimate of what the doctrine will be. The reality of time, however, forces us to pause long enough to take a calculated stab at determining the implications of history for the future.

We will not attempt to document, to any great degree, our predictions, as such documentation would, in itself, be based only on what has gone before, and therefore is subject to the same limitations and fallibilities which affect our own predictions.

This is how we see night air operations in counterinsurgency during the months and years to come:

Night air operations in future counterinsurgency wars will be conducted using equipment and forces available at that time. These resources will be employed using techniques appropriate to the geographical, political, military, and economic environment which we face. The best judgment of the military operators who are charged with the mission will be applied, with results being largely dependent on their knowledge, experience and training.

The emphasis which is currently being placed on night air operations will provide trained personnel and equipment designed, or specifically adaptable, for conduct of these operations. The capabilities of

these personnel and of this equipment will produce increasingly effective results in the employment of air power at night.

Although we may assume that with trained people, tailored equipment, and specific doctrine the conduct of future counterinsurgency warfare will be night oriented at the outset, we must recognize that a certain amount of groping will take place in the beginning of any insurgent war. Lieutenant Colonel M. W. Sutcliffe (British Army), in a Rand Corporation symposium observed that,

> The pattern of war changes. By the time it was possible to organize. . . good strikes, so many other things had happened that I think future operations might begin exactly the same as they did [in Malaya]. In the early stages you don't have contacts or information channels set up. You are fighting a sort of indiscriminate war in which you must take some action.[22]

This was the pattern in Vietnam and it will be repeated in future counterinsurgency wars. We can surmise, however, that the lessons of Vietnam will, to some extent, accelerate our ability to implement the most effective operations regardless of environment.

We can predict that greater emphasis will be placed on combined night operations employing highly trained small infantry units supported by pre-planned artillery, air, and naval gunfire. The air support will be a mix of low and high performance fighter-bombers, helicopters (armed and unarmed), and large and small cargo, liaison, and general support aircraft.

A Rand Corporation study on Tactical Aircraft for Limited War enumerated the following characteristics and capabilities which should be found in aircraft designed for counterinsurgency:

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[22]A. H. Peterson, G. C. Reinhardt, E. E. Conger, "Symposium on the Role of Airpower in Counterinsurgency and Unconventional Warfare: The Malayan Emergency," Memorandum RM-3651-PR (Santa Monica, California: The Rand Corporation, Jul 63), p. 57.

[redacted]

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[redacted]

Required Mission Capabilities	Vehicle Characteristics
Operate from remote, improvised bases.	Modest base-facility. Maintainability.
Deliver non-nuclear weapons. Minimize collateral damage.	Delivery accuracy. Carry large ordnance loads.
Achieve and maintain air superiority. Carry out armed reconnaissance. Conduct close support operations.	Extensive in-flight performance flexibility.
Rapid deployment to troubled area.	Long ferry range.

This study recognized the need to compromise in development of an aircraft and accept the fact that all of the capabilities and characteristics listed above would be difficult to obtain in a single aircraft.[23]

There are three approaches to the development of weapons and equipment for counterinsurgency. These approaches are included in the following comments: Air Commodore P. E. Warcup, C.B.E. (RAF), stated his position in a Rand symposium report.

> The services, being what they are, make equipment to fight various types of war, not one war. None of us, not even Americans, can afford specialized aircraft for each type of conflict. I think you will have to fight the war with the equipment you have for other types of war.[24]

Commander Turner F. Caldwell, Jr., USN, at the end of World War II, took a different position. He felt that, "the future night fighter, if we can

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[23] R. Schamberg, "Tactical Aircraft for Limited War," Memorandum RM-3545-PR (Santa Monica, California: The Rand Corporation, Mar 63), p. 6.

[24] A. H. Peterson, G. C. Reinhardt, E. E. Conger, op. cit., p. 82.

As a corollary to the preceding prediction, we see counterinsurgency operations becoming more offensive in nature. At the present time in Vietnam, this is more of a fact than a prophecy. Continuous operations, day and night, oriented on action rather than reaction are a present reality, with every indication pointing to further emphasis in this direction.

Air operations in counterinsurgency of the future will be increasingly diversified with greater emphasis on the use of aircraft for psychological warfare and in harassment roles. More and more emphasis will be placed on target selectivity in an attempt to obtain maximum results from the effort expended. Multiple mission sorties will be the rule, with secondary targets and missions assigned to each scheduled aircraft sortie. As equipment and weapons become more sophisticated, and hence more costly, the need for maximum utilization of each flying hour becomes a necessity.

Predictable tactics include increased use of illumination devices of all kinds with an ultimate objective of providing daytime environment for counterinsurgency forces on a 'round the clock basis. We can also foresee the employment of "hunter-killer" teams to a greater degree; teams consisting of flareships, fighter-bombers, reconnaissance and control aircraft, and armed helicopters, operating together in a coordinated effort directed toward finding, fixing, and destroying insurgent forces.

A fundamental responsibility of military forces is to provide our country with the most effective and efficient extension of its national objectives through military means when that means is necessary and called for. The use of air power at night in counterinsurgency has proven its value. In the future it will become a method of employment of air power

having major applications for counterinsurgency. The doctrine is evolving and will continue to evolve, to the benefit of those who recognize its promise.

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TECHNICAL MANUAL

OPERATOR'S AND ORGANIZATIONAL MAINTENANCE MANUAL

(INCLUDING REPAIR PARTS AND SPECIAL TOOLS LIST)

FLARE, AIRCRAFT: PARACHUTE, WHITE, MK 45 MOD 0 (FSN 1370-088-5658-L473); FLARE, AIRCRAFT: PARACHUTE, MK 45 MOD 0 WITH ADAPTER FOR DISPENSER XM19 (FSN 1370-461-1526-L424); AND DISPENSER, FLARE: XM19 (FSN 1370-179-6011-L106)

HEADQUARTERS, DEPARTMENT OF THE ARMY

JULY 1974

WARNING

Prior to takeoff, assure that seal on nitrogen cylinder of dispenser is not broken (i. e., valve pin is not protruding). If nitrogen gas has been expended, dispenser assembly cannot be jettisoned (see fig. 1–7 and para 2–4*b*).

TECHNICAL MANUAL
No. 9-1370-201-12

HEADQUARTERS
DEPARTMENT OF THE ARMY
WASHINGTON, DC, 25 July 1974

OPERATOR'S AND ORGANIZATIONAL MAINTENANCE MANUAL
(Including Repair Parts and Special Tools List)

FLARE, AIRCRAFT: PARACHUTE, WHITE, Mk 45 MOD 0 (FSN 1370-088-5658-L473), FLARE, AIRCRAFT: PARACHUTE, Mk 45 MOD 0 WITH ADAPTER FOR DISPENSER XM19 (FSN 1370-461-1526-L424), AND DISPENSER, FLARE: XM19 (FSN 1370-179-6011-L106)

*This manual supersedes TM 9-1370-201-12, 8 July 1969, including all changes.

LIST OF ILLUSTRATIONS

LIST OF TABLES

CHAPTER 1

INTRODUCTION

Section I. GENERAL

1-1. Scope

This manual provides the user with operating instructions and organizational maintenance procedures for parachute aircraft flare Mk 45 Mod 0 (DODIC L473), parachute aircraft flare Mk 45 Mod 0 with adapter (DODIC L424), and flare dispenser XM19.

1-2. Forms, Records and Reports

a. Forms. Maintenance forms, records, and reports which are to be used by maintenance personnel at all maintenance levels are listed in and prescribed by TM 38-750.

b. Field Report of Accidents. Accidents involving injury to personnel or damage to materiel will be reported on DA Form 285 (Accident Report) in accordance with AR 385-40.

c. Report of Damaged or Improper Shipment. Materiel received in damaged or otherwise unsatisfactory condition because of deficiencies in preservation, packaging, marking, loading, storage, or handling will be reported on DD Form 6 (Report of Packaging and Handling Deficiences) in accordance with AR 700-58. Reports of improper shipment or damage caused by transportation discrepancies will be reported on SF 361 in accordance with AR 55-38.

d. Malfunctions Involving Explosives.

(1) Ammunition malfunction reports from Army activities will be reported as prescribed in AR 75-1.

(2) A malfunction is the failure of a pyrotechnic item to function in accordance with the expected performance when fired, or when explosive components function during a nonfunctional test. A critical malfunction is one which may cause a hazard in the circumstances described above. Malfunctions do not include accidents and incidents resulting from negligence, malpractice, or implication in other situations such as vehicle accidents or fires. However, malfunctions do include abnormal or premature function of pyrotechnic items during normal handling, maintenance, storage, transportation, and tactical deployment.

(3) If a malfunction involving this material occurs, *firing of the affected lot will be halted immediately.* The commanding officer or senior individual in charge of the unit will immediately contact the officer under whose supervision the ammunition for the unit involved is maintained or issued and will report all available facts concerning the malfunction.

1-3. Recommendation for Maintenance Publications Improvements

You can help to improve this manual by calling attention to errors and by recommending improvements. Your letter or DA Form 2028 (Recommended Changes to Publications and Blank Forms) should be mailed direct to Commander, Picatinny Arsenal, ATTN: SARPA-AD-M-F, Dover, NJ 07801. A reply will be furnished direct to you.

1-4. Destruction of Ammunition to Prevent Enemy Use

Destruction of pyrotechnics when subject to capture or abandonment will be undertaken by the user only when, in the judgment of the unit commander concerned, such action is necessary in accordance with orders of, or policy established by, the Army commander. (Refer to TM 750-244-5-1.)

Section II. DESCRIPTION AND DATA

1-5. Flare, Aircraft: Parachute, White, Mk 45 Mod 0 and Flare, Aircraft: Parachute, Mk 45 Mod 0 with Adapter for Dispenser XM19

a. General. The flares covered by this manual are pyrotechnic devices which provide illumination in the two-million candlepower range for a period of approximately 3 1/2 minutes. The flares are launched from helicopters. Flare identification and method of launching is shown in table 1-1.

b. Description.

(1) Parachute aircraft flare MK 45 Mod 0 and Mk 45 Mod 0 with adapter (fig. 1-1) are identical except for minor variations. The basic design consists of a candle assembly, a parachute assembly, and a suspension/ignition assembly in an aluminum case, to which is assembled an ejection fuze assembly. The characteristics of the flares are shown in table 1-2.

Table 1-1. Identification and Method of Launching Flares

Nomenclature	DODIC	Method of launch
FLARE, AIRCRAFT: parachute, white Mk 45 Mod 0.	L473	Launched by hand only.
FLARE, AIRCRAFT: parachute, Mk 45 Mod 0 with adapter for dispenser XM19.	L424	Launched by flare dispenser XM19 or by hand.

(2) The fuze assembly, which controls candle and parachute ejection, extends 2 1/4 inches beyond the case. The fuze consists of an internal disconnect, a striker and plunger assembly, a 2-second (nominal) fixed delay element, a time delay fuse, an ejection charge, and a fuze setting mechanism. The fuze setting mechanism consists of a yellow ejection dial indicator, with 15 different setting points marked in black on the face of the fuze. The setting points range from 500 to 14,000 feet. (A decal on the case gives fuze setting and safing information.) Raised projections at SAFE and at each setting point facilitate setting the fuze in total darkness. A spring-loaded detent holds the ejection dial indicator at the selected setting.

(3) The parachute assembly consists of a drogue chute, a main parachute, and a deployment bag in a split cardboard container.

(4) The suspension/ignition assembly connects the parachute and candle assemblies. A firing pin, a primer, and an ignition pellet constitute the ignition assembly. The suspension assembly consists of a cable extending from the main parachute to an explosive bolt at the candle end.

Table 1-2. Characteristics of Mk 45 Flares

Diameter (max)	4.87 in.
Length (max)	36.0 in.
Weight	28 lb
Candlepower (avg)	2 million
Burning time (avg)	210 sec
Minimum delay (fuze set at 500 ft)	3.0 sec
Rate of descent	7.5 fps

(5) The 18-pound candle assembly consists of a paper tube containing a magnesium candle and a detonator.

(6) A plastic shipping cap covers the fuze end of the assembled flare and protects the fuze area during shipment and storage.

(7) Minor variations in the fuze components of the flares are as follows:

(*a*) Flare Mk 45 Mod 0 (fig. 1-2) has a stainless steel lanyard assembly with a double coil at one end and a swivel eye at the other end, coiled under the plastic shipping cap. A swivel snaphook is attached to a loop in the lanyard about 4 1/2 inches from the double coil. A black plastic lanyard retainer is attached to the lanyard adjacent to the swivel snaphook. A two-pronged safety clip holds the toggle in place in an aluminum housing in the center of the fuze. A yellow tag, attached to the prongs of the safety clip by a split key ring, warns the user not to remove the safety clip.

(*b*) Flare Mk 45 Mod 0 with adapter does not use a lanyard assembly and toggle with the fuze. Instead, a pull cable assembly is used (fig. 1-3).

c. Functioning.

WARNING

Since the outer case falls free after ejection, creating a missile hazard, use of flares over inhabited friendly territory is not recommended.

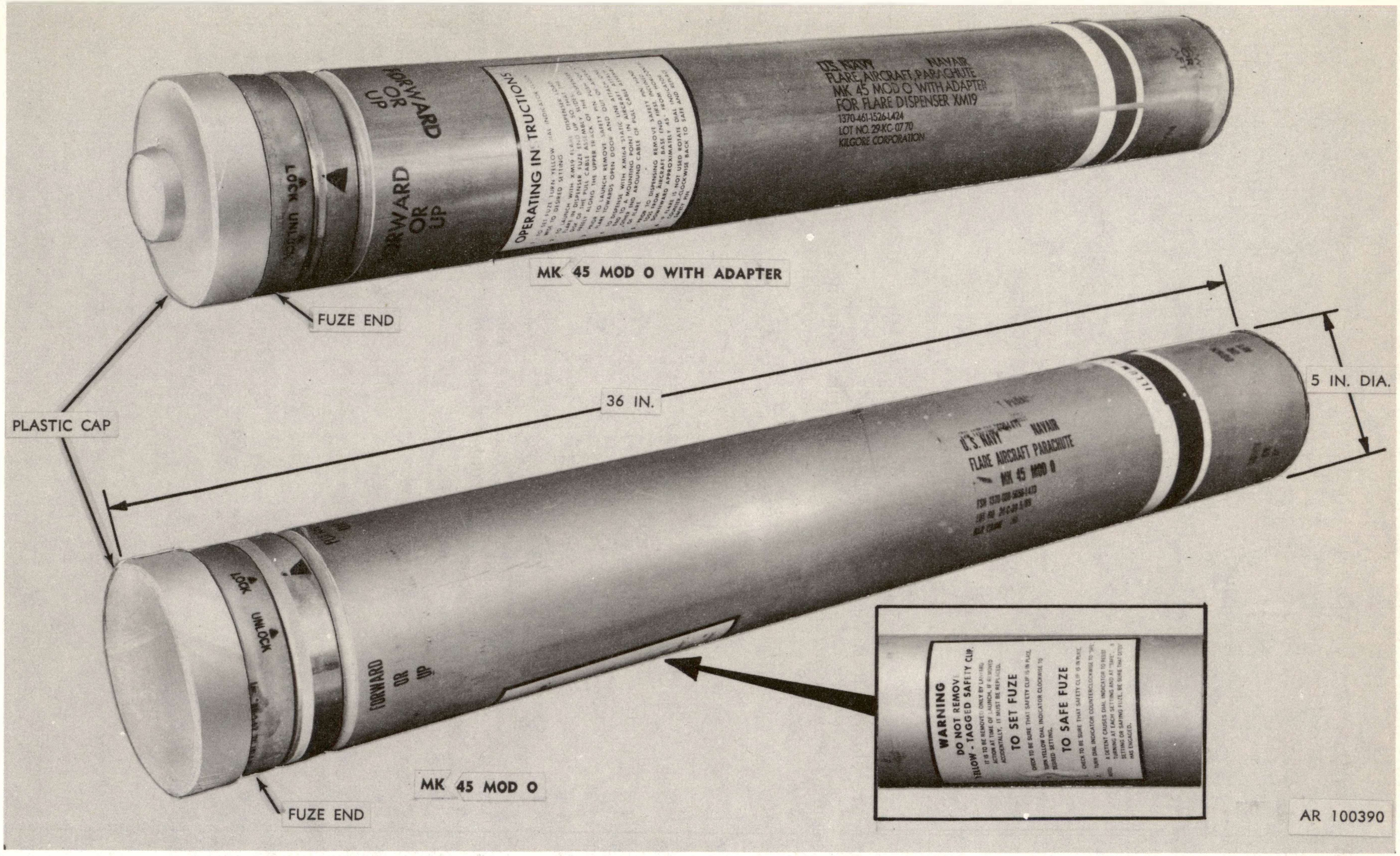

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Figure 1–1. Parachute aircraft flares Mk 45 Mod 0 and Mk 45 Mod 0 with adapter.

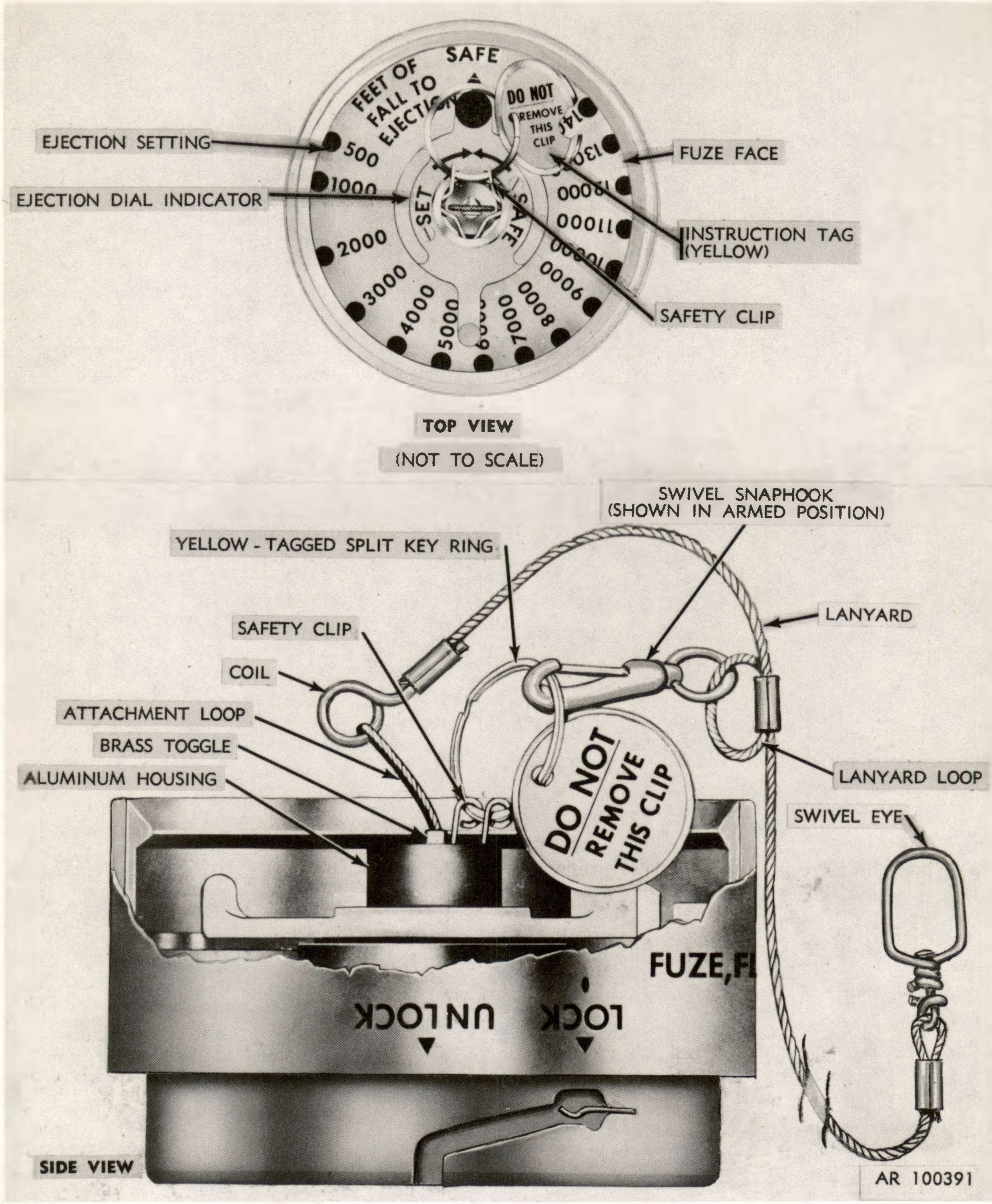

Figure 1–2. Fuze for parachute aircraft flare Mk 45 Mod 0.

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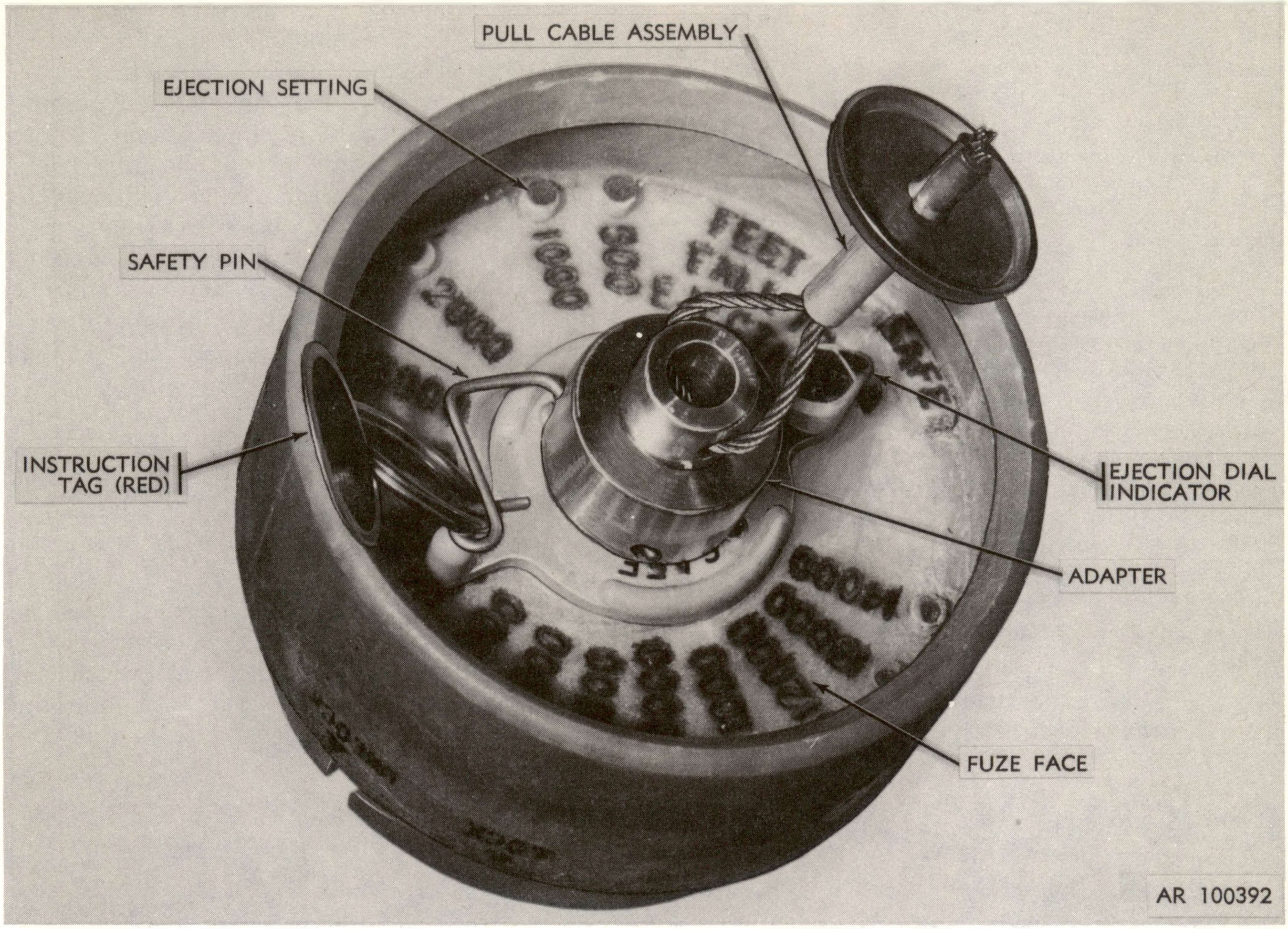

Figure 1–3. Fuze for parachute aircraft flare Mk 45 Mod 0 with adapter.

(1) When the flare is launched, the internal disconnect is pulled from the fuze, allowing the spring-loaded striker to initiate the primer in the base of the plunger. The primer ignites the 2-second delay element and drives the plunger into the fuse cord. The delay element ignites black powder in the plunger. The burning powder ignites the fuse cord, which ignites the ejection charge, exerting sufficient pressure against the gas check to blow off the end cap and eject the parachute and candle assemblies.

(2) The drogue chute deploys and separates the main parachute from its deployment bag. When the main parachute opens, it exerts a pull on the cables of the suspension/ignition system. The shorter of the cables pulls a release pin from the igniter assembly. This cocks and releases the firing pin so that it strikes the primer in the suspension/ignition assembly. The primer initiates the ignition pellet which ignites the magnesium candle.

(3) Near the end of its burning time, the heat of the candle initiates the explosive bolt, which fragments. This releases many of the shroud lines, collapsing the parachute and allowing the burned-out flare to fall rapidly to the ground.

1–6. Dispenser, Flare: XM19

a. General. The flare dispenser XM19 is intended to facilitate the launching of parachute aircraft flares from helicopters. It is installed inside the helicopter, serves as a storage rack, and is equipped with a gas-operated mechanism which, in time of emergency, permits jettison of the dispenser assembly, including flare load, from the helicopter. The flare dispenser XM19 is restricted to use with the parachute aircraft flare

Mk 45 Mod 0 with adapter. The characteristics of the dispenser are shown in table 1-3.

Table 1-3. Characteristics of Flare Dispenser XM19

Length:	
Overall, with snout retracted	81 in.
Overall, with snout extended	118 in.
Width	16 in.
Height	46 in.
Weight:	
Dispenser	230 lb
Jettison assembly	80 lb
Dispenser assembly	150 lb
Full flare load (24 flares)	672 lb
Dispenser (with 24 flares)	902 lb
Pneumatic System:	
Nitrogen cylinder (filled)	2,500 psi
Weight of nitrogen	0.2 lb
Piston:	
Length	6 feet
Diameter	1 in.

b. Description.

(1) The dispenser consists of a dispenser assembly and a jettison assembly, including a test set for XM19, a firing panel, a cable, and tiedown hardware.

(2) The dispenser assembly (fig. 1-4) is designed to accommodate 24 flares in an upright position. It has an extendable snout for launching, a channel-shaped stainless steel base tray, and an overhead track for holding and guiding the flares. The extruded aluminum frame consists of side supports with loading and dispensing gates. The overhead track, which conforms to the channel pattern of the base tray, consists of two parallel guides. The guides are spaced so that the flare pull cable assembly can slide in between, while the disk in the pull cable assembly rides on top of the guides. The snout, which is at the dispensing end of the overhead track, is extended when dispensing flares and is retracted during storage, shipment, and flight (fig. 1-5). The removable loading gate at the other end of the overhead track is held in place by a latch. The dispensing gate is a bar located at the intersection of the overhead track.

(3) The jettison assembly (figs. 1-6 and 1-7) includes a track plate with rails on either side. The dispenser assembly rides on rollers which fit into the rails. Mounting points are located on the track plate to match the tiedown fittings on the

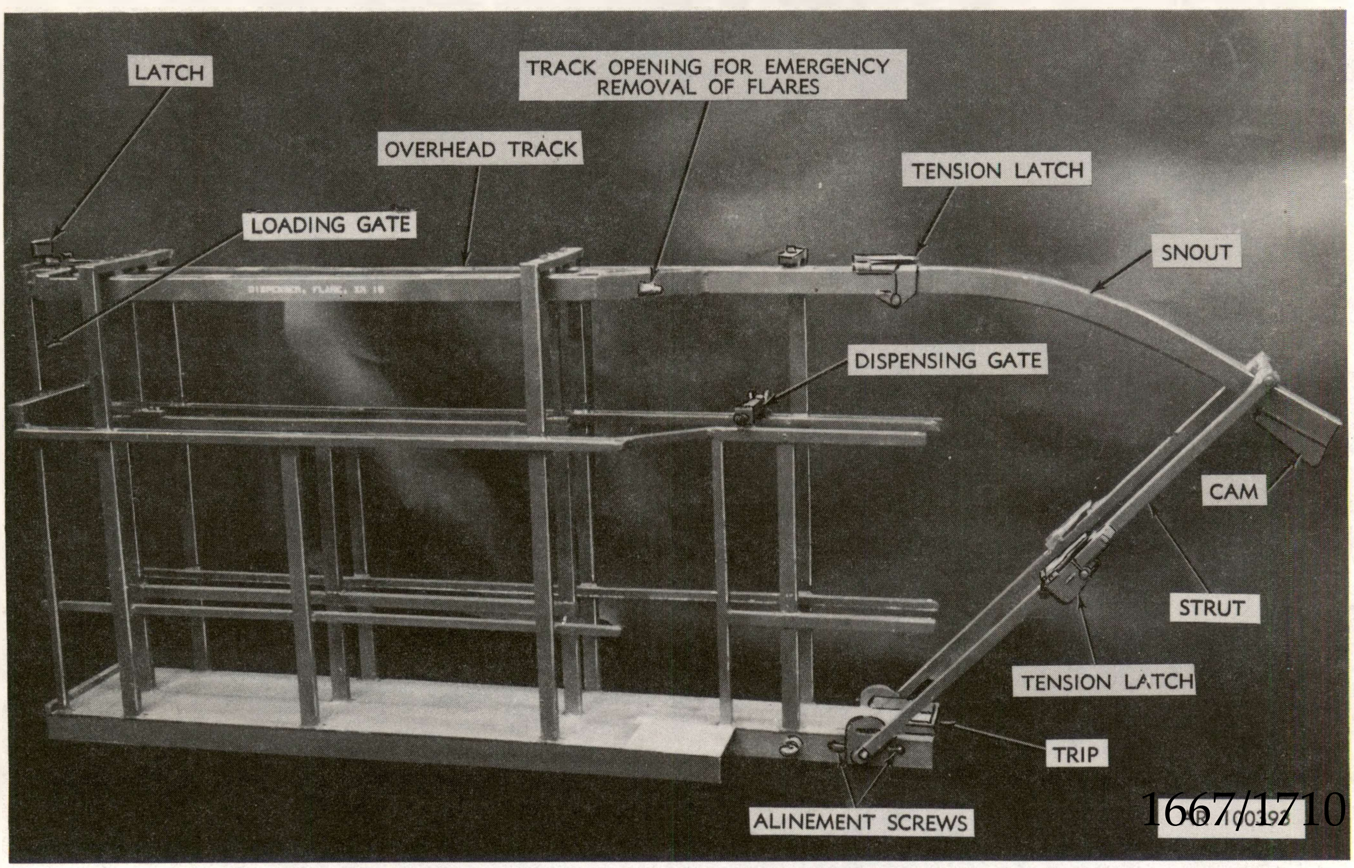

Figure 1-4. Dispenser assembly of flare dispenser XM19.

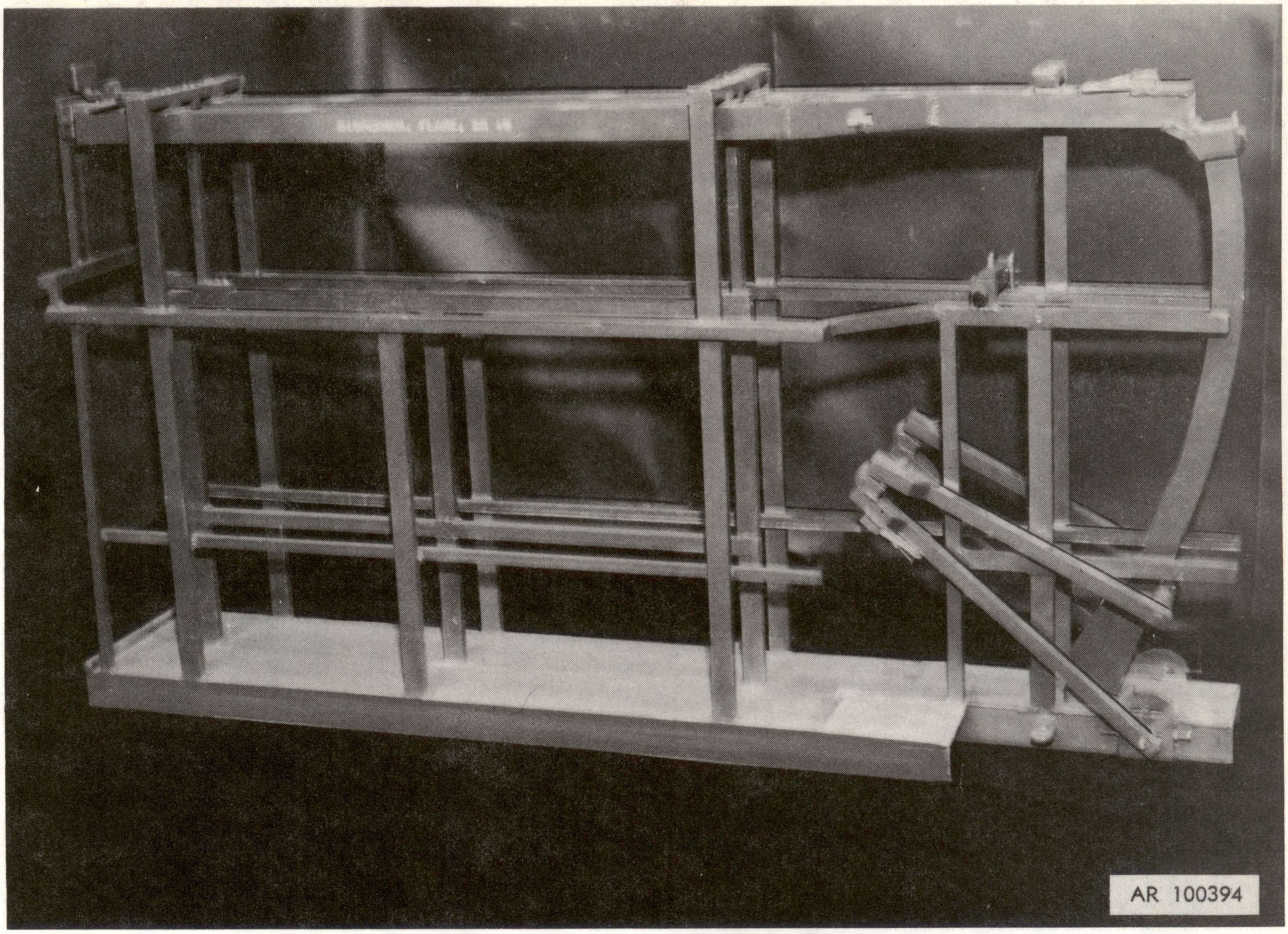

Figure 1-5. Dispenser assembly of flare dispenser XM19—snout retracted.

floor of helicopters (UH-1B, UH-1C, UH-1D, and UH-1H. A cylinder containing nitrogen gas under pressure of 2,500 psi supplies the power for jettison. A safety valve is used to prevent inadvertent jettison action. Two interlocks secure the dispenser assembly to the track plate. A piston, with the forward end painted red, provides jettison action. A hole in the piston tube permits inspection for the piston.

(4) The firing panel (fig. 1-8) consists of a hand-operated firing device which is mounted on the instrument panel. A safety switch precludes accidental jettison of the dispenser. A bail provides a positive mechanical lock to prevent inadvertent depression of the firing device handle. A cable is provided to connect the firing panel to the nitrogen cylinder.

(5) Test set for XM19 is needed for electrical continuity testing.

(6) Snap-on fittings and nuts are used to attach the track plate to the helicopter floor.

c. Functioning.

(1) *Using Flare Dispenser XM19 to Launch Parachute Aircraft Flare Mk 45 Mod 0 with Adapter.* When the dispenser is loaded with flares (fig. 1-9), the pull cable assembly is held by the overhead track, while the full weight of the flare rests on the base tray. To launch the flare, the body of the flare is pushed along the base tray toward the extended snout, while the pull cable assembly slides along the overhead track. The flare is tripped at the end of the base tray, and the pull cable assembly slides down the snout until it simultaneously pulls the flare away from the trip and the pull cable assembly engages the cam. The weight of the flare against the cam separates the pull cable assembly from the flare, arming the flare.

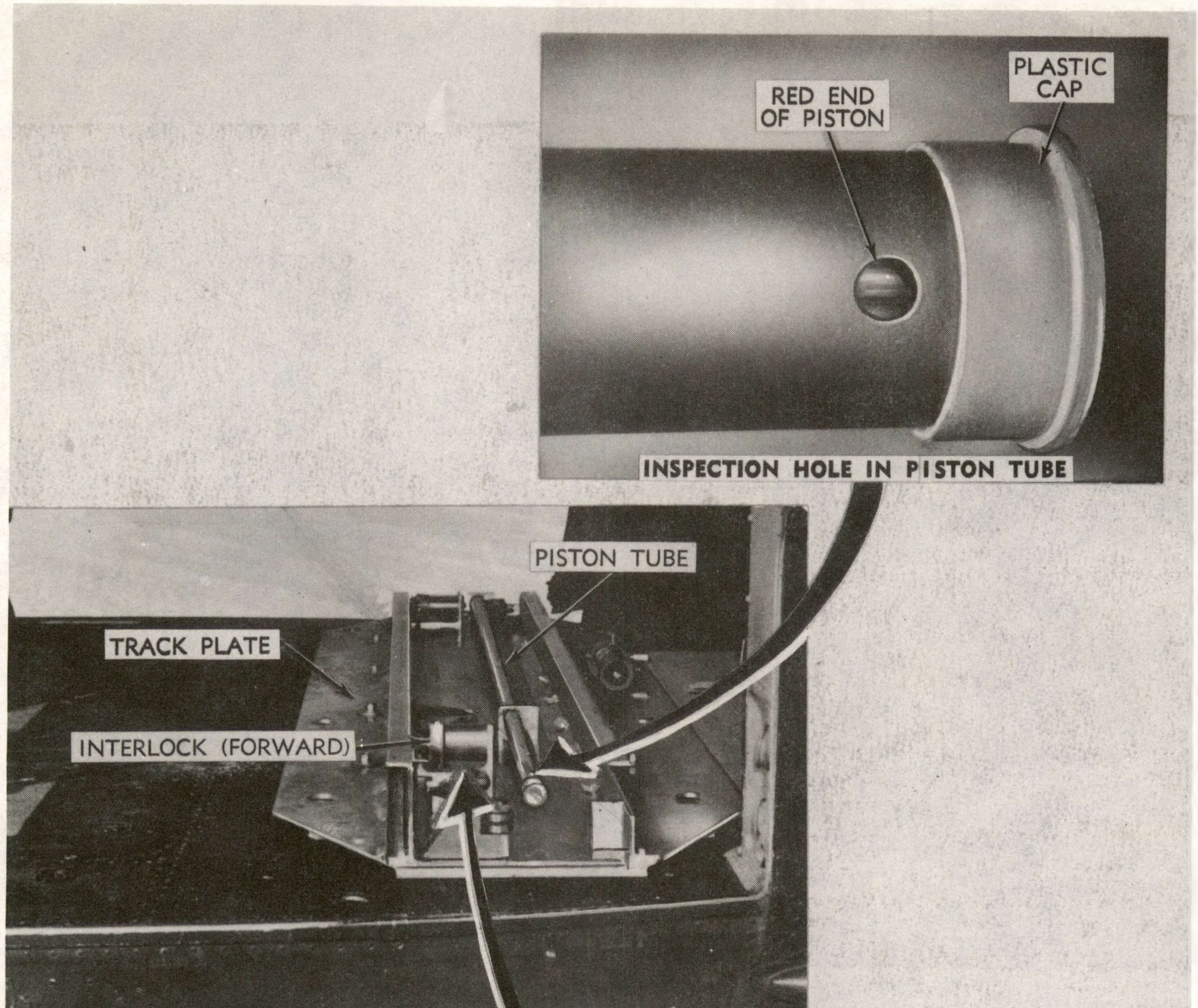

Figure 1-6. Jettison assembly of flare dispenser XM19—view from right side of helicopter.

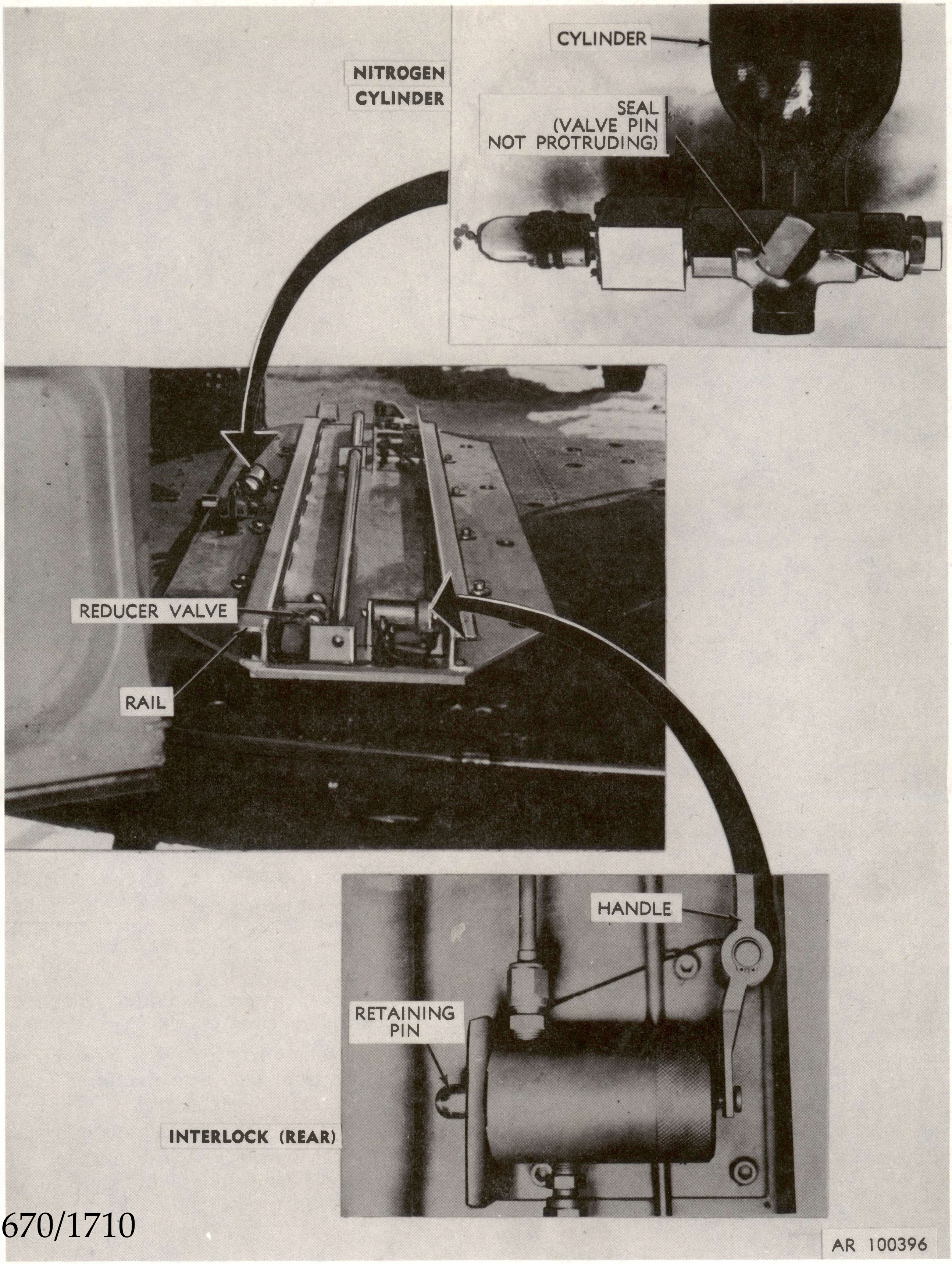

Figure 1-7. Jettison assembly of flare dispenser XM19—view from left side of helicopter.

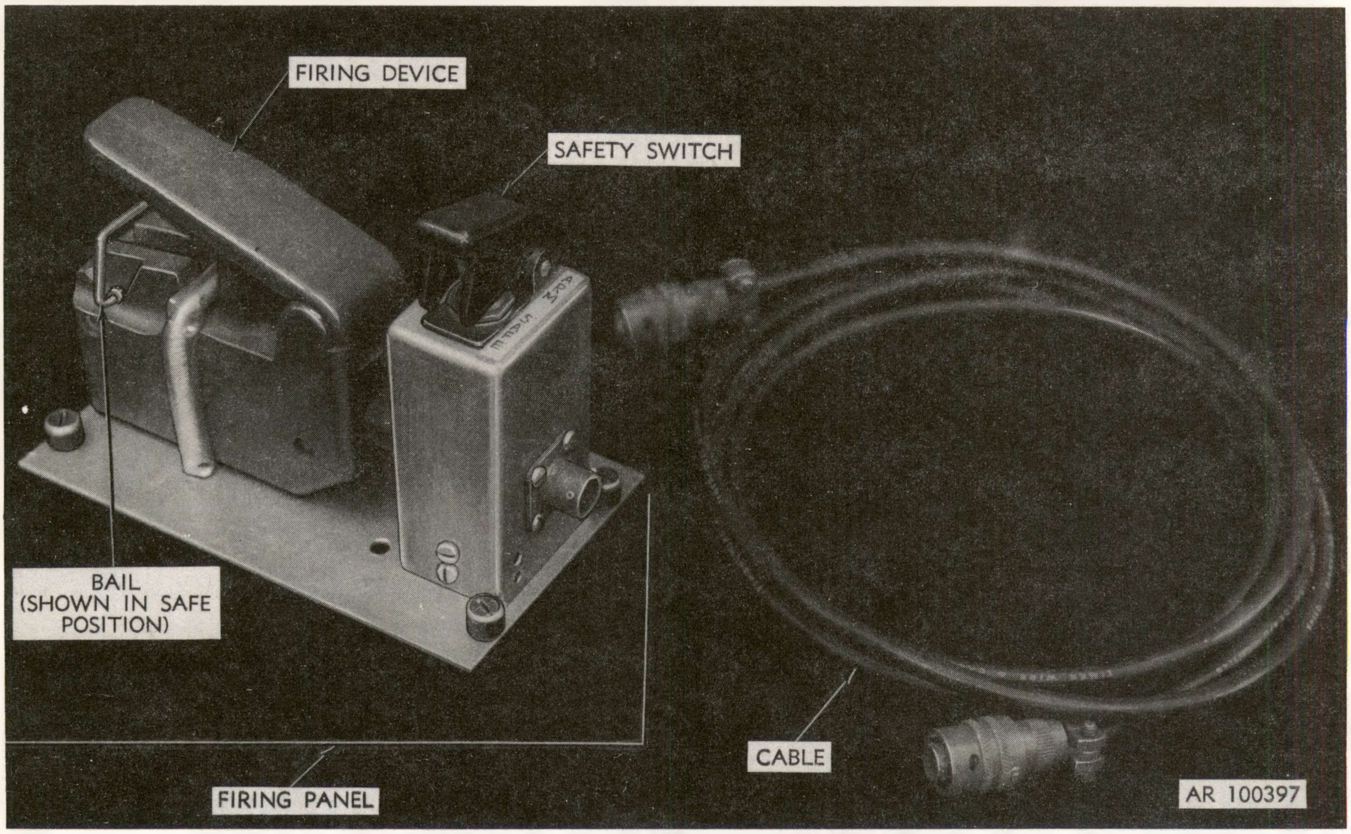

Figure 1-8. Firing panel and cable of flare dispenser XM19.

(2) *Jettisoning dispenser assembly and flares.* Once the dispenser assembly has been positioned on the track plate, it is manually secured with interlocks. Immediately after takeoff, the pilot rotates the bail out from under the handle of the firing device and a crew member turns the safety valve handle to the ARM position. If it becomes necessary to jettison the dispenser, the pilot lifts the safety switch cover, turns the switch to the ARM position, and strikes the handle of the firing device with the palm of his hand. An electrical signal is generated and transmitted through a circuit to a squib connected to the top of the nitrogen bottle mounted on the track plate. Upon initiation of the electrically fired squib, nitrogen gas under pressure of 2,500 psi is released. The gas passes through steel tubing to the safety valve. With the safety valve handle rotated to the ARM position, the gas is diverted to the interlocks on the underside of the dispenser assembly, unlocking it from the track plate. The gas passes through a reducer valve, decreasing the pressure to 475 psi. This pressure, acting on the head of the piston, propels the dispenser assembly out of the right-side door opening of the helicopter in 0.8 seconds.

1-7. Accessory Item Required for Hand Launching Flares

Flare drop static line XM164 is used for hand launching. It is a steel wire reinforced molded plastic strap with a snaphook at each end. The flat contour of the static line affords a low floor profile to prevent accidental tripping. Static line XM164 may be requisitioned by using Federal Stock Number 1370-962-1798.

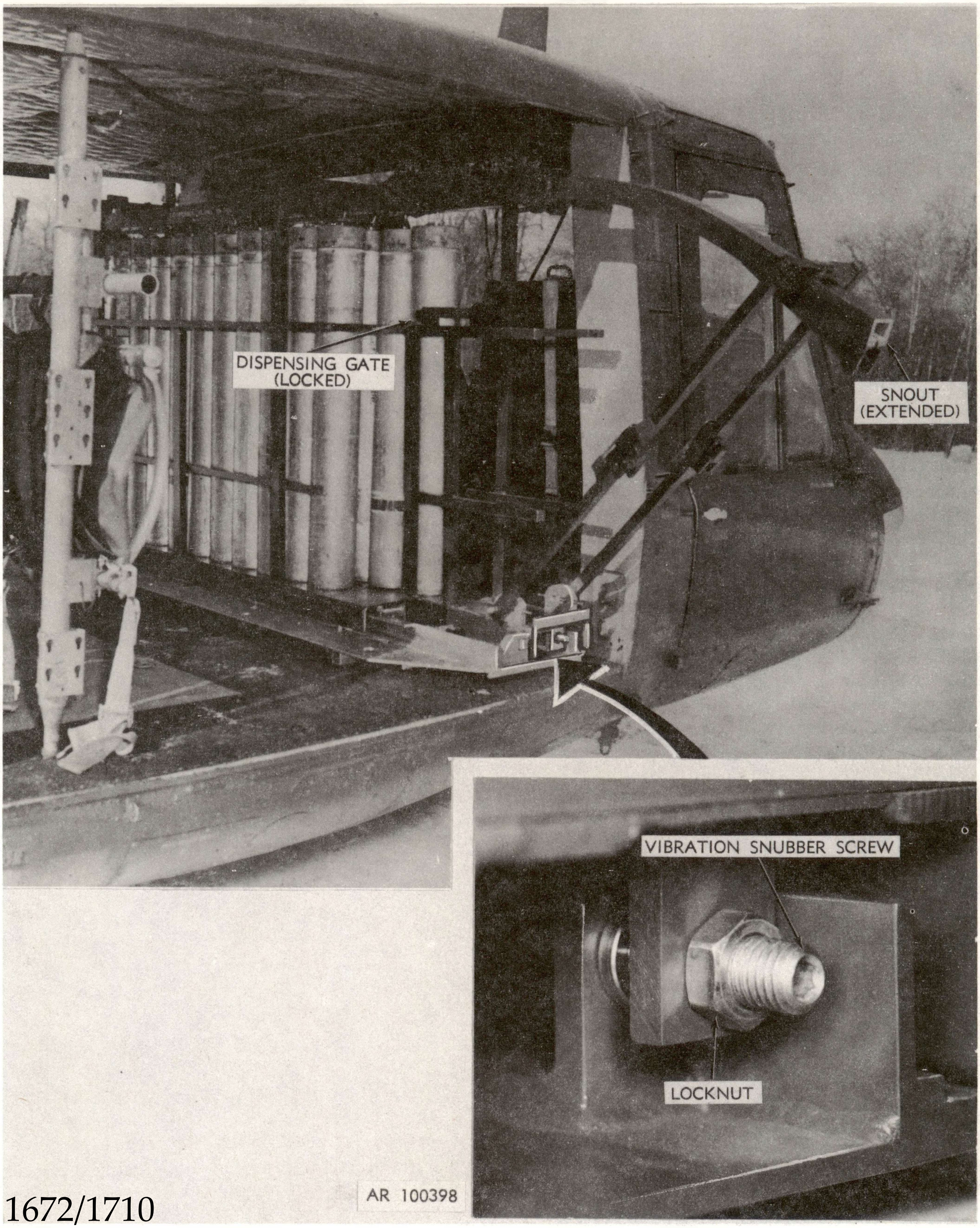

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Figure 1-9. Flare dispenser XM19—installed in helicopter and loaded with flares.

Section III. SAFETY, CARE, AND HANDLING

1-8. Safety

WARNING

Alteration of flares is prohibited.

a. Handle flares with utmost care at all times.

b. Do not drop, drag, throw, tumble or otherwise strike boxes containing flares.

c. Exercise care if flares show evidence of moisture inside the flare container. Contact authorized disposal personnel for disposal of flares that have been exposed to moisture. Moisture may cause a dud or generation of hydrogen if it penetrates the flare.

d. Avoid exposing flares to extreme temperatures, such as below −65° F. or above +160° F.

e. Consider flares with damaged fuzes hazardous. Contact authorized disposal personnel immediately for disposal.

f. Do not touch, move, or otherwise handle duds; their fuzes may be armed. Contact authorized disposal personnel for disposal.

g. Flares should not be left in helicopter indefinitely. When flares are left in a helicopter temporarily or removed from a helicopter, check fuzes to assure that ejection dial indicators are set on SAFE. For Mk 45 Mod 0, assure that swivel snaphook is *not* engaged with the split key ring, and that safety clip is properly seated. For Mk 45 Mod 0 with adapter, assure that safety pin is in place.

1-9. Care and Handling

CAUTION

The flare is easily dented, which may result in non-ejection or faulty ejection of the candle.

Flares are packed to withstand conditions ordinarily encountered in the field. Although the polystyrene containers (fig. 1-10) provide adequate protection for shipment and storage, observe the following:

a. Keep polystyrene containers from becoming broken or damaged.

b. Repair or replace broken containers immediately and re-mark those bearing illegible markings.

c. Protect flares against such foreign matter as mud, sand, moisture, frost, snow, ice, dirt, oil, and grease. Wipe off any foreign matter at once.

d. Do not open containers until flares are to be used.

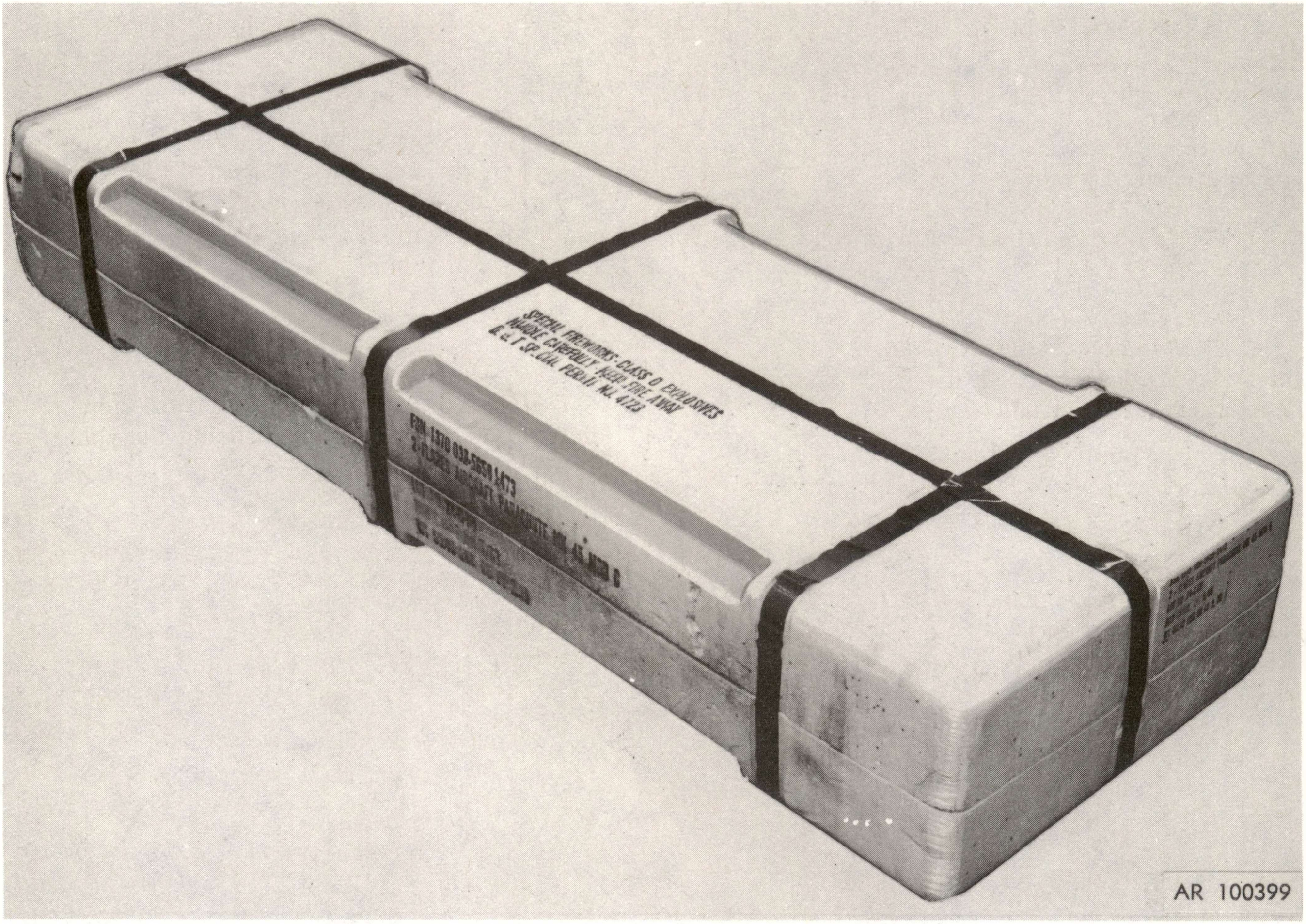

Figure 1-10. Container for flares.

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CHAPTER 2

OPERATING INSTRUCTIONS

Section I. OPERATION UNDER USUAL CONDITIONS

2-1. General Precautions—Mk 45 Mod 0 and Mk 45 Mod 0 with Adapter

WARNING

Inadvertent flare function during handling could cause serious injury to personnel and damage to equipment.

a. Do not use flares with cracked, dented, or deformed cases.

b. Removal of fuzes under any circumstances is prohibited. Have flares containing damaged fuzes removed by authorized disposal personnel.

c. Observe firing temperature limits of +145° F. and −65° F.

d. Avoid unseating safety clip/pin. If safety clip/pin becomes unseated, or is inadvertently removed, replace it in aluminum housing before proceeding. If clip/pin is missing and if replacement is unavailable, do not pull lanyard or pull cable assembly; turn flare over to authorized disposal personnel. A pull on lanyard of 30 pounds or a pull on pull cable of 200 pounds can cause fuze to function. If fuze is set at any delay setting, such pull will cause case and candle to separate violently after the delay; if set on SAFE, fuze will become permanently inoperable.

e. If flare is accidentally ejected on ground, wind force of 35 knots will cause drogue chute to remove deployment bag and release main parachute. Attempt to keep parachute from opening. Cut shroud lines and dispose of candle tube.

f. If parachute opens accidentally, deflate by collapsing parachute. Do *not* hold candle tube. The parachute could drag *unrestrained* candle tube without causing ignition, provided pull on candle does not exceed 60 pounds, which may actuate candle.

2-2. Mk 45 Mod 0

a. Preparation for Use.

(1) Remove tape from container, lift top half, and remove flares.

(2) Remove plastic cap (A, fig. 2-1) from fuze end of flare.

WARNING

If safety clip is unseated or missing, do not pull lanyard.

(3) Assure that safety clip is in place and ejection dial indicator is set on SAFE.

(4) Visually inspect flare for damage. Contact authorized disposal personnel for disposal of damaged flares.

NOTE

If flare is shipped with lanyard attached, simply uncoil lanyard, and proceed to step (7) below. If lanyard is not attached, perform steps (5) and (6) before continuing with step (7).

(5) Remove and uncoil lanyard. Remove lanyard retainer and retain for replacement if flare is not expended.

(6) Connect coil on end of lanyard to attachment loop and toggle in fuze (B, fig. 2-1).

WARNING

For launch from aircraft operating below 70 knots indicated airspeed (KIAS), a minimum fuze setting of 1,000 feet shall be used.

(7) Using forefinger of right hand and thumb of left hand, set ejection dial indicators (C, fig. 2-1) by turning clockwise to desired setting (table 2-1). A spring-loaded detent holds ejection dial indicator at each setting and aids in setting fuze in darkness since engagement of the detent can easily be felt.

Figure 2-1. Attaching lanyard and setting fuze.

Table 2-1. Approximate Aircraft Altitudes (Thousands of Feet) for Ejection at 2,500 Feet Above Target Area

Fuze settings	Ground elevation of target area—thousands of feet above sea level: 0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	
500	3.0	4.0	4.9	6.0	7.1	8.1	9.1	10.1	Altitude of aircraft at time of drop (above sea level)
1,000	3.4	4.5	5.5	6.5	7.6	8.6	9.7	10.7	
2,000	4.5	5.6	6.7	7.7	8.8	10.0	11.0	12.2	
3,000	5.6	6.7	7.8	9.0	10.1	11.3	12.5	13.6	
4,000	6.5	7.7	8.9	10.0	11.3	12.5	13.8	15.1	
5,000	7.4	8.6	9.9	11.1	12.4	13.6	15.0	16.4	
6,000	8.2	9.5	10.8	12.1	13.5	14.8	16.2	17.5	
7,000	9.1	10.4	11.8	13.1	14.5	15.9	17.4	19.0	
8,000	10.0	11.4	12.8	14.3	15.6	17.1	18.8	20.4	
9,000	10.9	12.4	13.8	15.3	16.8	18.4	20.1		
10,000	11.8	13.3	14.9	16.4	18.1	19.8			
11,000	12.9	14.4	16.0	17.7	19.4				
12,000	13.9	15.5	17.3	19.0					
13,000	15.0	16.7	18.5	20.5					
14,000	16.2	18.0	20.0						

Use of the table: Find the column for the elevation of the target area above sea level. In this column, find the line for the altitude of the aircraft above sea level. On this line, find the fuze setting in the left hand column.

Example:

1. Elevation of target area 4,000 feet, desired aircraft altitude 10,000 feet—set fuze for 3,000 feet.

2. Elevation of target area 1,000 feet, desired aircraft altitude 15,500 feet—set fuze for 12,000 feet.

(8) Extend lanyard over edge of fuze and secure with a 15 1/2-inch strip of tape to outside of fuze case, leaving lanyard loop and swivel snaphook just above edge of fuze (D, fig. 2–1), in line with yellow-tagged key ring on safety clip.

(9) Replace plastic cap, holding lanyard inside cap (A, fig. 2–2).

(10) Coil remainder of lanyard around outer container (B, fig. 2–2) and secure swivel eye to case with type (C, fig. 2–2).

(11) Using grease pencil, mark ejection fuze setting on case.

Figure 2–2. Replacing plastic cap and securing lanyard to case.

NOTE

Flare is now ready for loading in interior of helicopter.

b. Operation.

WARNING

Crewmen engaged in hand launch operations will wear harness and be secured to aircraft by safety line.

WARNING

Do not connect snaphook to yellow-tagged key ring until just before launching flare.

(1) For emergency use, stow spare static lines XM164 on board the helicopter.

(2) Secure flares adequately to prevent movement during flight.

(3) Attach static line XM164 to cargo tiedown near door.

(4) Launch flares as follows:

(*a*) Remove tape securing lanyard to case and uncoil lanyard. Stick tape to side of case.

(*b*) Attach free end of static line XM-164 to swivel eye of lanyard (A, fig. 2–3).

WARNING

Exercise extreme caution to avoid pulling safety clip during next step. If safety clip is pulled, toss flare from helicopter immediately.

(*c*) Remove plastic cap. Attach swivel snaphook to yellow-tagged key ring (B, fig. 2–3), holding ring firmly and pressing down on ring with snaphook.

CAUTION

Flares which hit skid of helicopter may fail to function.

(*d*) Throw flare from helicopter (fig. 2–4), base end first, assuring that flare clears helicopter.

WARNING

If flare does not separate from static line XM164, do *not* attempt to pull flare back into helicopter. Detach static line from tiedown ring and let both items fall away.

(*e*) Retrieve static line and discard lanyard. Retain static line for future use.

c. Prepared for Use but Not Launched. Flares which were prepared for use but not launched

Figure 2–3. Preparing fuze for launch.

will be returned to their original condition as follows:

(1) Remove plastic cap.

(2) Assure that safety clip is present in each flare.

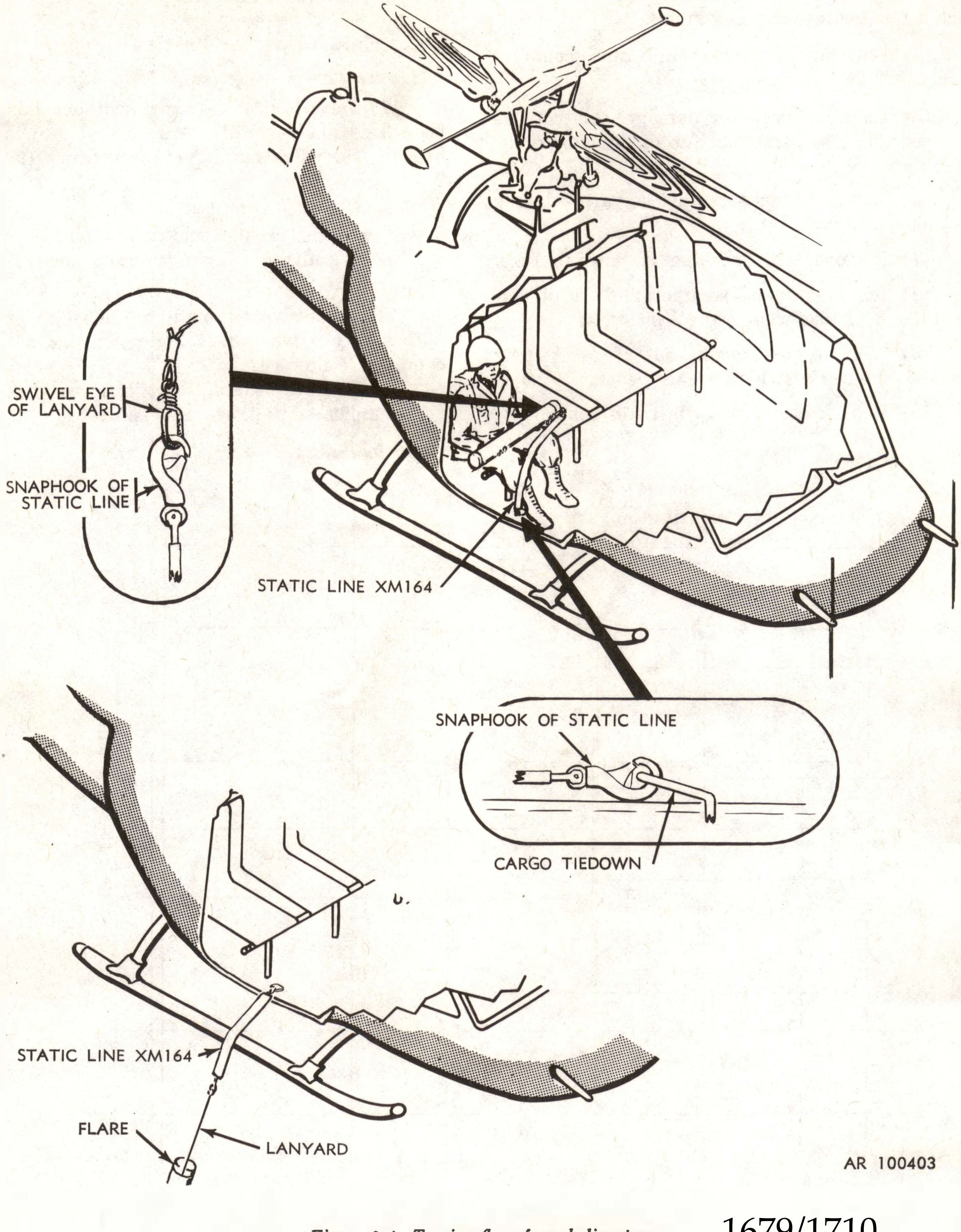

Figure 2-4. Tossing flare from helicopter.

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(3) If flare has been hooked up for launch, assure that lanyard swivel snaphook is disconnected from safety clip key ring.

(4) Turn ejection dial indicator counterclockwise to SAFE position.

(5) Examine flare for damage. Contact authorized disposal personnel for disposal of damaged flares.

(6) Remove tape securing lanyard to case and uncoil lanyard.

(7) Remove tape securing lanyard to fuze.

(8) Install lanyard retainer and recoil lanyard inside of fuze well; replace plastic cap.

(9) Remove or block out fuze setting marked on outer case with grease pencil.

(10) Repack serviceable flares in containers. Replace tape on containers. Use repacked flares first in subsequent launchings.

2–3. Flare Dispenser XM19

a. Installation of Jettison Assembly.

(1) Assure that nitrogen cylinder has not been fired inadvertently. Assure that seal is not broken and valve pin is not protruding (fig. 1–7).

NOTE

If seal is broken and valve pin protrudes, nitrogen cylinder must be replaced.

(2) Mount track plate on helicopter floor with safety valve end facing right side of helicopter as follows:

(*a*) Mate snap-on fittings to tiedown points indicated in figures 2–5 and 2–6.

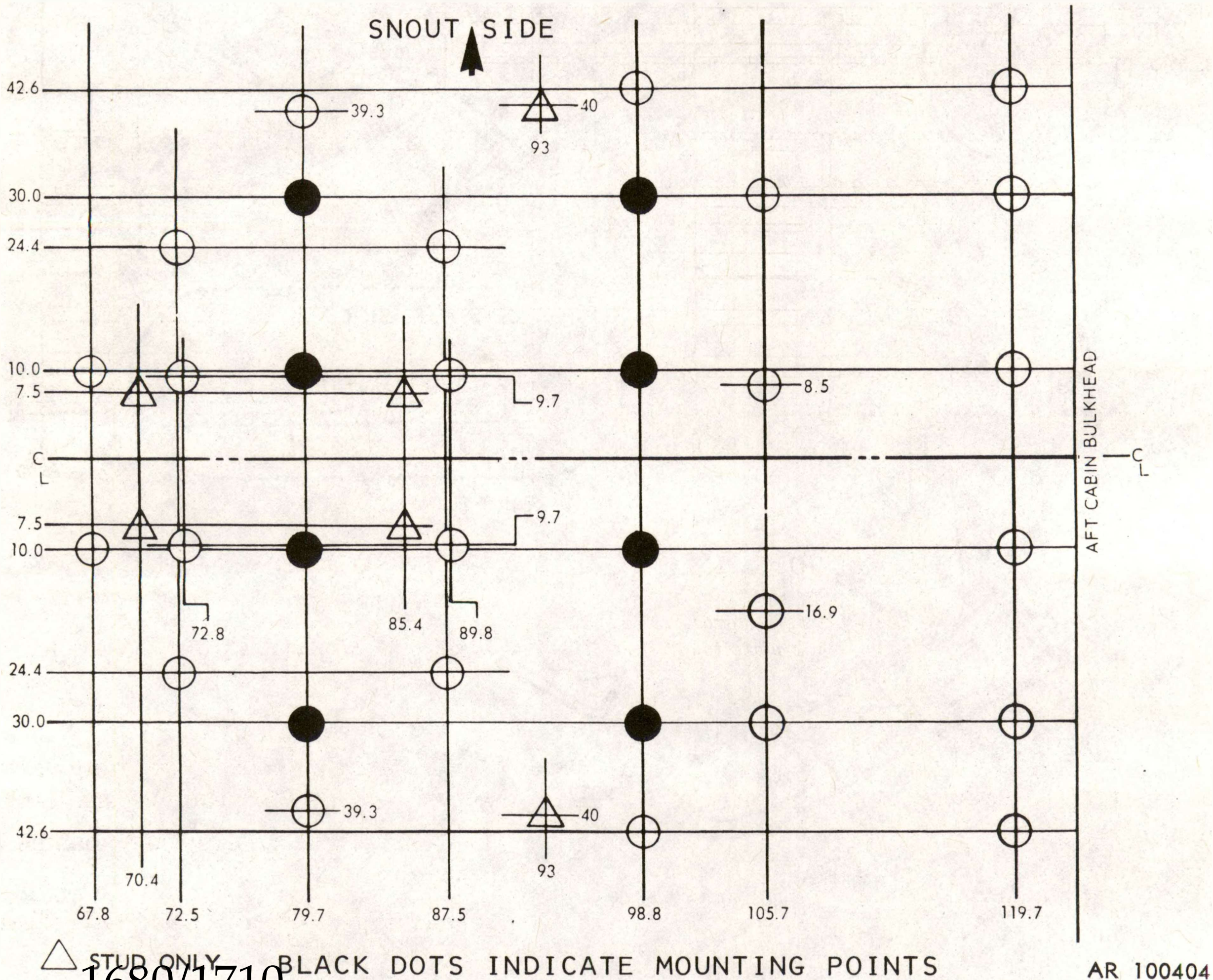
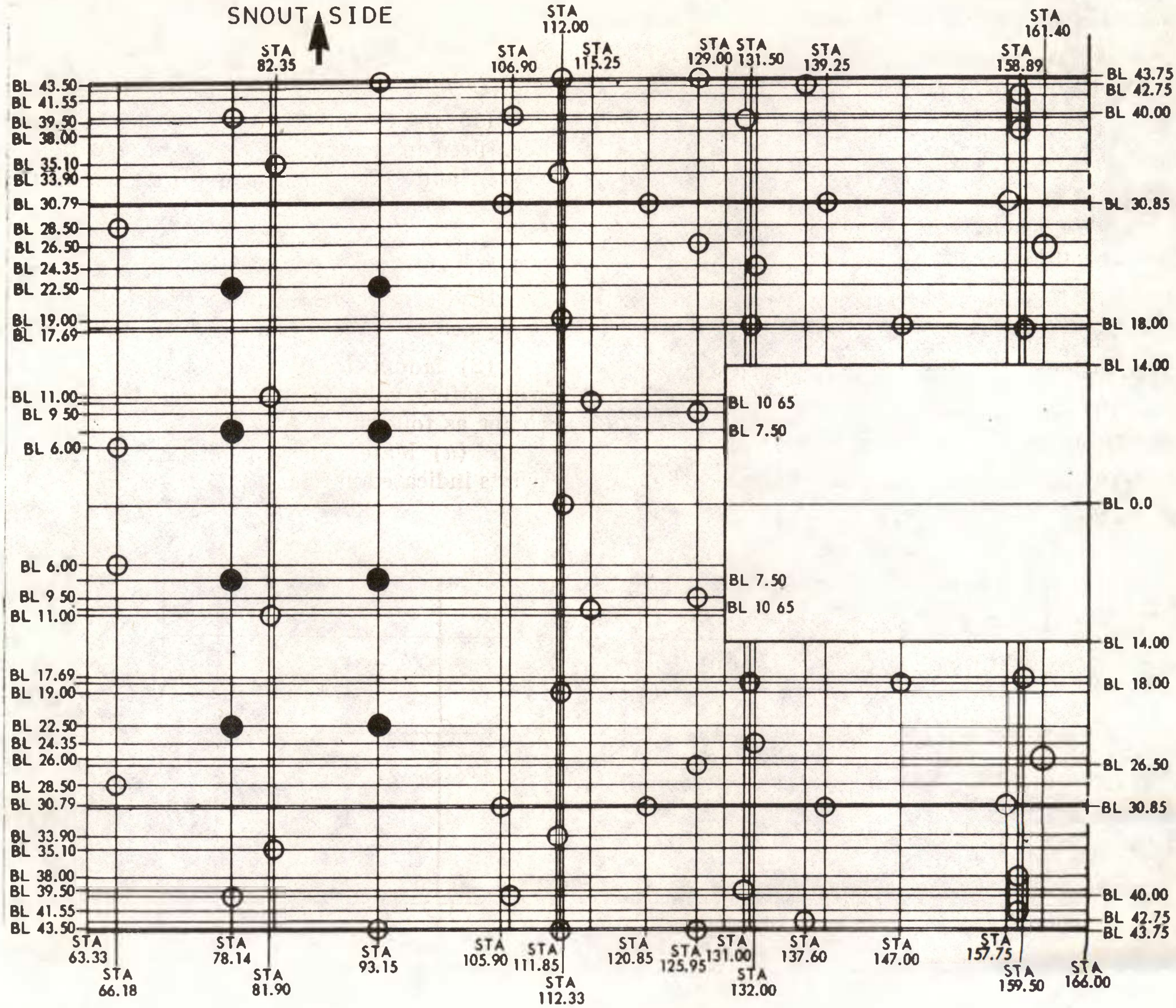


Figure 2–5. Diagram showing mounting points for securing track plate to floor of helicopter models UH–1B and UH–1C.



BLACK DOTS INDICATE MOUNTING POINTS

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Figure 2–6. Diagram showing mounting points for securing track plate to floor of helicopter models UH–1D and UH–1H.

(*b*) Position track plate so that mounting holes and snap-on fittings are alined.

(*c*) Bolt track plate firmly in place with hexagon nuts.

(3) Assure that piston is in proper position by looking into inspection hole (fig. 1–6). (Red end of piston should be visible.)

(4) Mount firing panel on instrument panel in most convenient position for pilot use by locking snap-screws of firing panel.

(5) Attach cable to firing panel and electrical connector on nitrogen cylinder (fig. 2–7).

WARNING

Prior to testing, assure that safety valve handle is in SAFE position (fig. 1–6).

(6) Assure that safety valve handle is in SAFE position.

b. Performing Electrical Continuity Test Using Test Set for XM19.

(1) Disconnect cable from firing panel and insert test set between firing panel and cable (fig. 2–8).

(2) Rotate bail out from under handle of

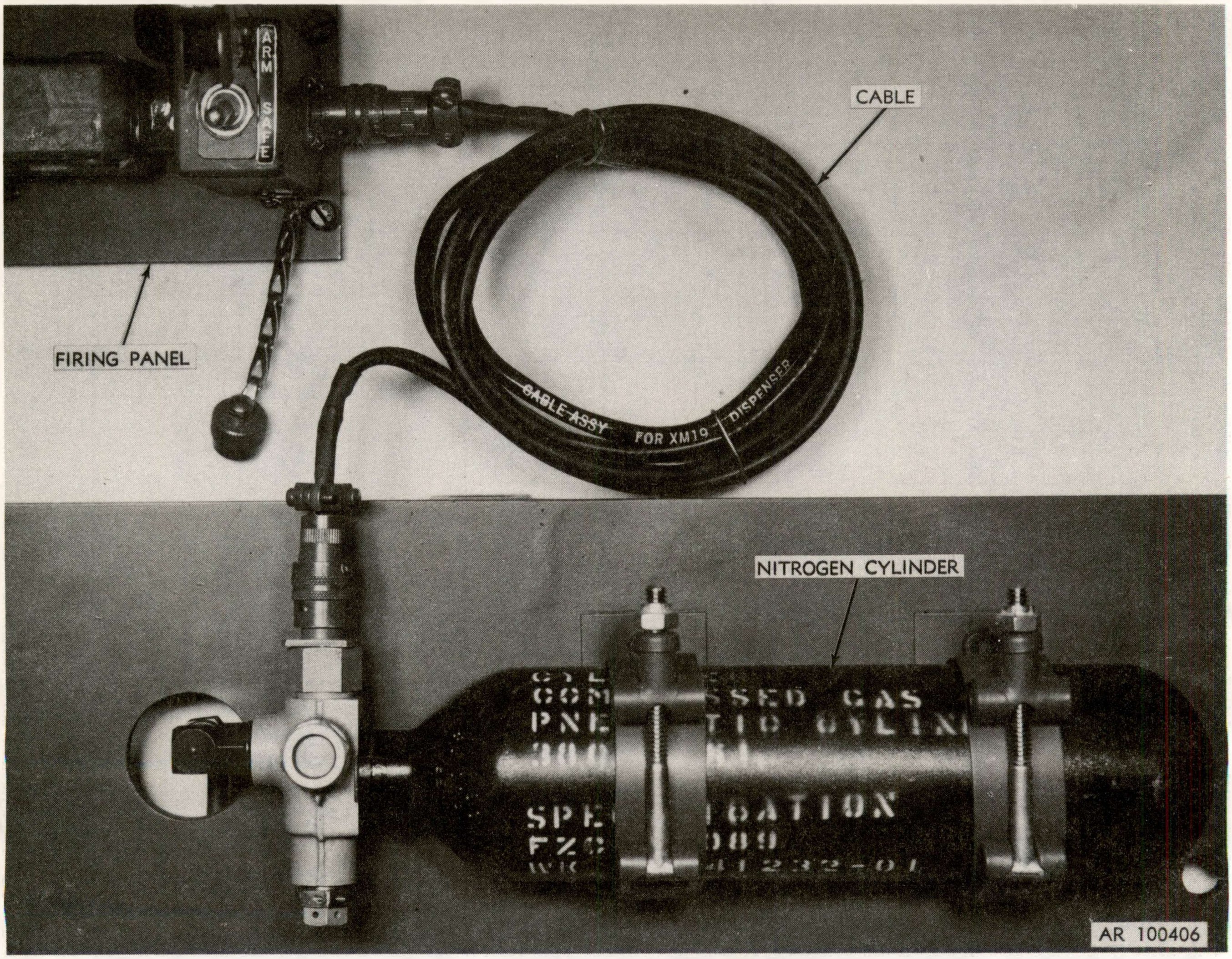

Figure 2-7. Cable connected to firing panel and nitrogen cylinder.

firing device and turn safety switch to ARM position. Depress handle of firing device by exerting firm, quick pressure, and observe flashing of lamp through test set window. Flashing of lamp indicates that total electrical circuitry is functioning. If lamp does not flash, a component or the test set is defective.

NOTE

Window of test set should be held near eye when checking firing panel. It improves ability of operator to see lamp flashing even in bright sunlight.

(3) After completion of test, place safety switch in SAFE position, close cover, and rotate bail back to locked position under handle of firing device.

(4) Remove test set and reconnect cable to firing panel.

c. Installation of Dispenser Assembly.

(1) Assure that the two interlocks of the jettison assembly are unlocked (figs. 1-6 and 1-7).

(2) Check rollers on underside of dispenser assembly to make sure that they rotate freely.

(3) Roll unloaded dispenser assembly onto track plate. Snout (retracted) must be at right-side opening of helicopter.

(4) Roll dispenser assembly back to mechanical stop.

(5) Verify that vibration snubber screw (fig. 1-9) is fully extended to counterclockwise position.

(6) Manually engage retaining pins by moving interlock handles towards rail.

(7) Turn vibration snubber screw clockwise

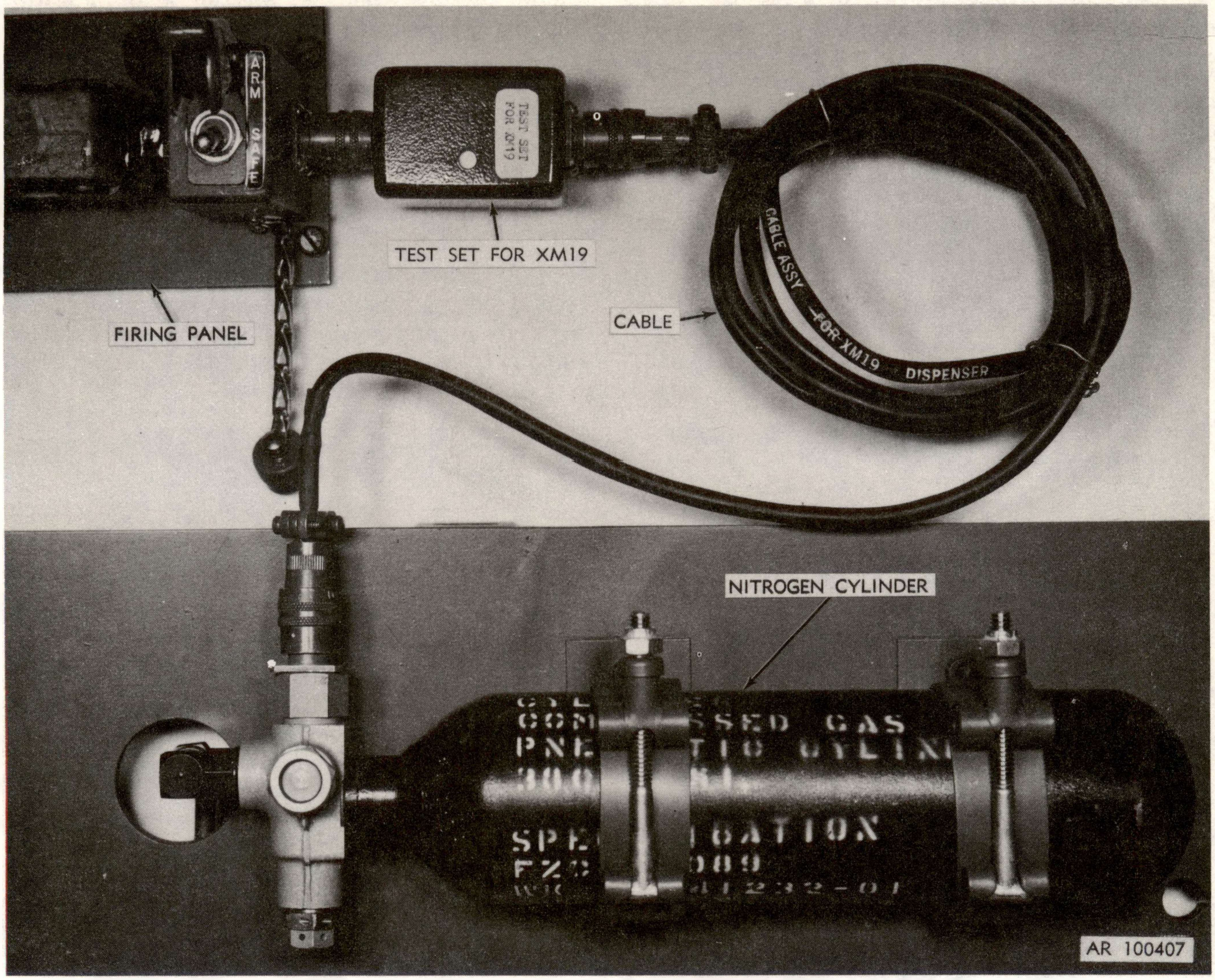

Figure 2-8. Continuity test setup for flare dispenser XM19.

fingertight in order to remove all lateral backlash movement of dispenser assembly, and secure screw with its locking nut.

(8) Unfold snout so that it extends through right-side opening and secure by locking strut and snout tension latches. To properly secure latches, it may be necessary to again aline screws at bottom of struts.

d. Preparation for Use. Prior to every mission, perform following inspections or tests.

(1) Perform electrical continuity test described in paragraph 2-3*b*.

(2) Assure that seal on nitrogen cylinder is unbroken.

(3) Assure that bail is under firing device handle.

(4) Assure that safety switch is in SAFE position with cover down.

(5) Assure that safety valve handle is in SAFE position.

2-4. Mk 45 Mod 0 With Adapter

a. Preparation for Use.

NOTE

Only flare Mk 45 Mod 0 with adapter can be launched from flare dispenser XM19.

(1) Remove tape from container, lift top half, and remove flares.

(2) Remove plastic cap from fuze end of flare.

(3) Assure that safety pin is in place and that ejection dial indicator is set on SAFE.

(4) Visually inspect flare for damage. Contact authorized disposal personnel for disposal of damaged flares.

WARNING

For launch from aircraft operating below 70 knots indicated airspeed (KIAS), a minimum fuze setting of 1,000 feet shall be used.

(5) Using forefinger of right hand and thumb of left hand, set ejection dial indicator (fig. 2–3) by turning clockwise to desired setting (table 2–1). A spring-loaded detent holds the ejector dial indicator at each setting and aids in setting fuze in darkness, since engagement of the detent can easily be felt.

(6) Remove loading gate of dispenser assembly by releasing latch and lifting gate off support pins.

(7) Load flare (fig. 2–9) into dispenser assembly by putting pull cable assembly in overhead track and pushing flare along base tray until it is against dispensing gate.

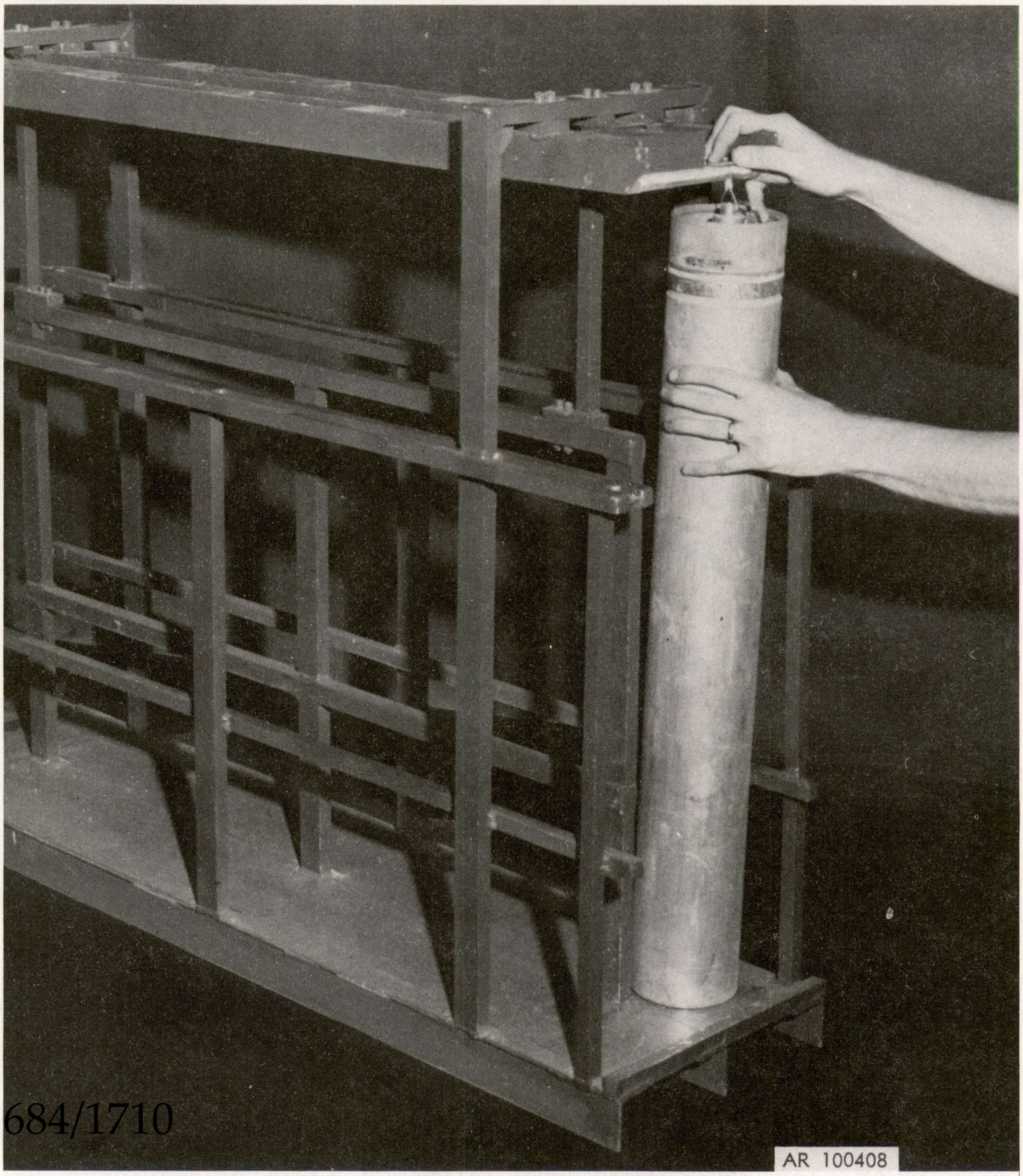

Figure 2–9. Loading flare on dispenser assembly.

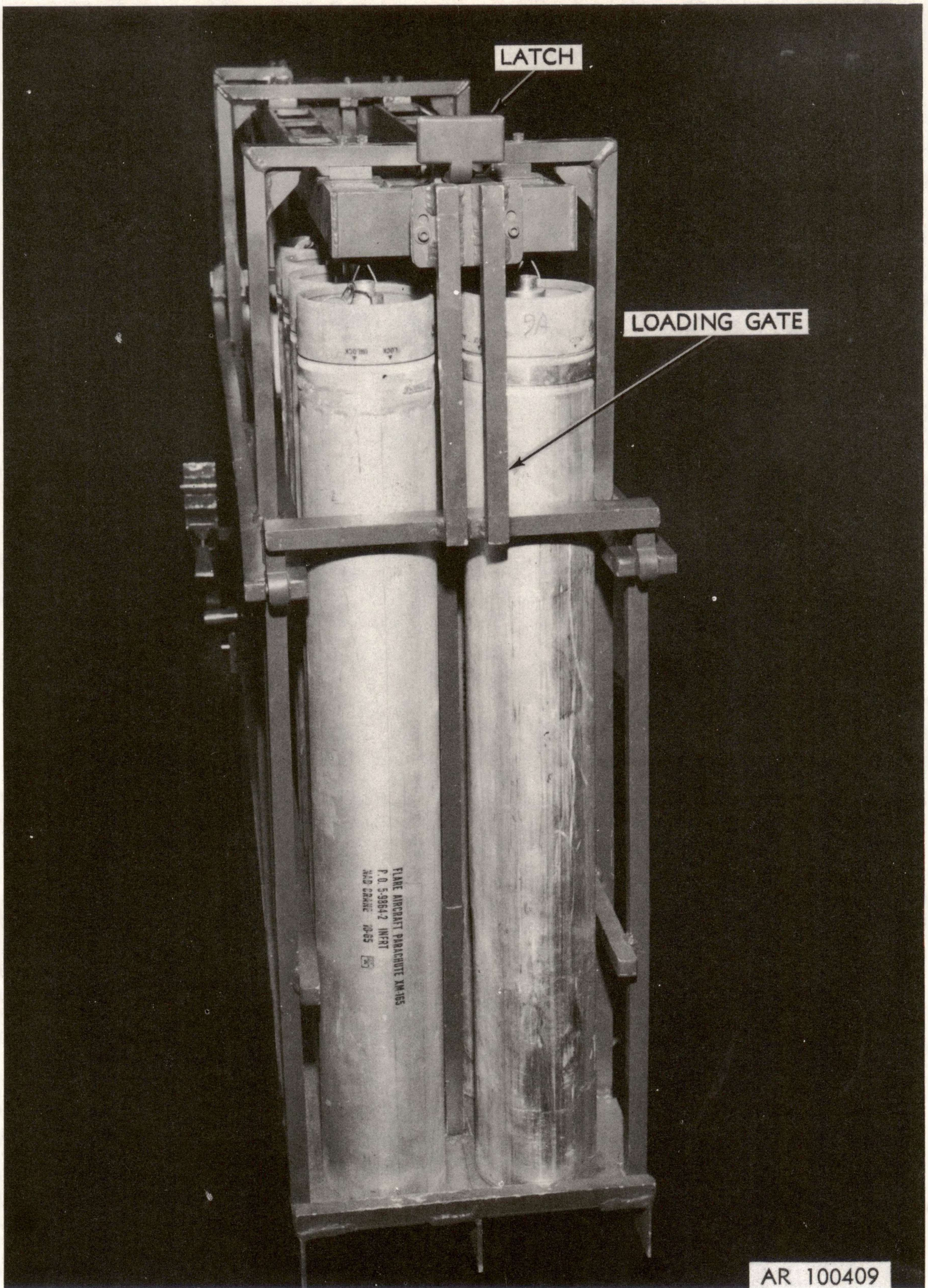

Figure 2-10. Loading gate installed (after loading of flares).

(8) When dispenser assembly has been loaded to capacity (24 flares), replace loading gate by setting gate on support pins and closing latch (fig. 2-10).

(9) Stow spare static lines XM164 on board helicopter for possible use if dispenser becomes inoperable during mission.

b. Operations.

WARNING

Prior to takeoff, assure that seal on nitrogen cylinder of dispenser is not broken (i.e., valve pin is not protruding). If nitrogen gas has been expended, dispenser assembly cannot be jettisoned.

WARNING

Crewmen engaged in launch operations will wear harness and be secured to helicopter by safety line.

(1) Immediately after takeoff, prepare for possibility of jettisoning dispenser assembly by rotating bail out from under handle of firing device and turning safety valve handle to ARM position.

WARNING

Dispense flares singly to prevent jamming in snout and possible functioning in helicopter.

NOTE

When not dispensing flares, close dispensing gate to prevent loss of flares in flight.

(2) Launch flares as follows:

(*a*) Remove safety pin from fuze (fig. 2–11) and retain for reinsertion if flare is not launched.

(*b*) Unlock dispensing gate.

(*c*) Move flare into position by pushing along base tray until it reaches dispensing gate.

(*d*) Push fuze end of flare in direction of cam (fig. 2–12) so that upon release, pull cable slides down snout and base of flare is pulled free of the trip.

NOTE

If safety pin has been left in inadvertently, the base of flare will pass the trip, but will hang from end of snout without dropping. Flare can be released by kicking flare near base end in a direction away from helicopter.

(3) Just before landing, rotate bail back under handle of firing device and turn safety valve handle to SAFE position.

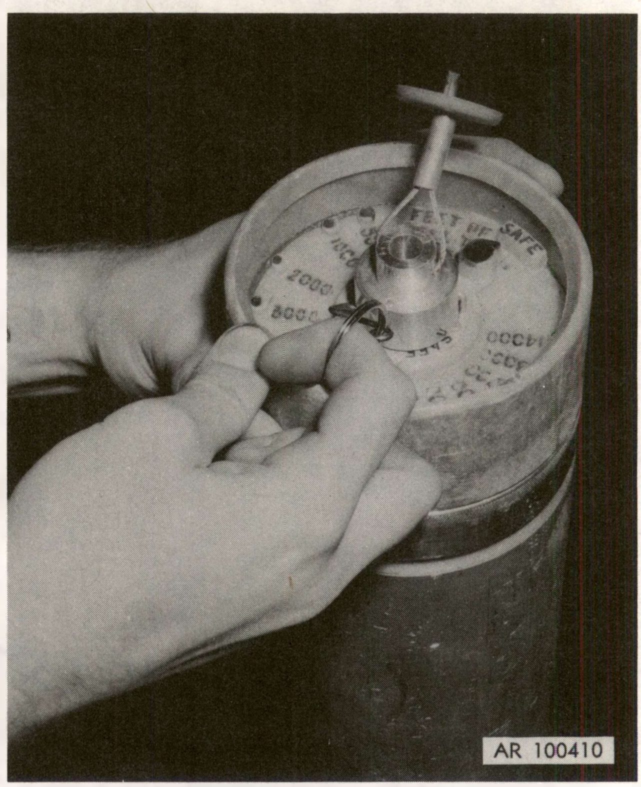

Figure 2–11. Removing safety pin.

c. Prepared for Use but Not Launched.

(1) Lock dispensing gate to retain flares not used on mission.

(2) Just before landing, rotate bail back under handle of firing device and turn safety valve handle to SAFE position.

(3) After landing, remove loading gate.

(4) Assure that a safety pin is present in each flare (fig. 2–13).

(5) Remove flares from dispenser assembly and turn ejection dial indicator counterclockwise to SAFE position. Examine flares for damage. Contact authorized disposal personnel for disposal of damaged flares.

(6) Repack serviceable flares in containers. Replace tape on containers. Use repacked flares first in subsequent launchings.

(7) Replace loading gate.

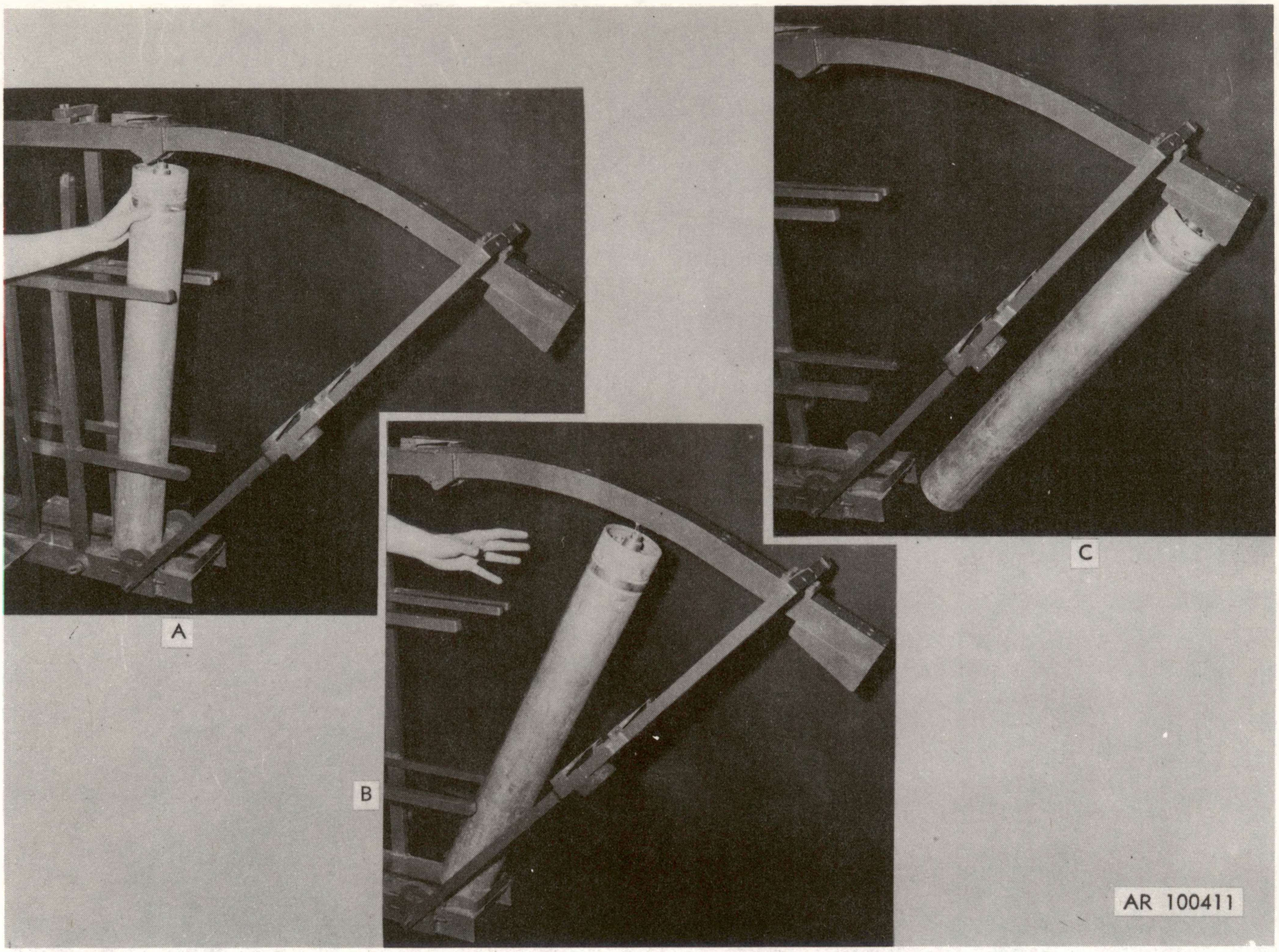

Figure 2-12. Launching sequence.

Figure 2-13. Reinstalling safety pin.

Section II. OPERATION UNDER UNUSUAL CONDITIONS

2-5. General—Mk 45 Mod 0 and Mk 45 Mod 0 with Adapter

Operation of flare under unusual conditions is the same as under normal conditions, with the following exception: During operation in Arctic environments, preparation procedures must be accomplished in warm structure to facilitate fuze setting and taping procedures. At extremely cold temperatures, the ejection dial indicator may become frozen in place, making setting difficult.

2-6. Mk 45 Mod 0 with Adapter

a. Procedure for Removing Flares When Dispenser Becomes Inoperable In Flight.

(1) Disengage pull cable assembly disk from overhead track of dispenser assembly (fig. 2-14).

(2) Assure that a safety pin is present in each flare (fig. 2-13). Tilt top of flare rearward and remove flare through emergency release opening (fig. 2-15).

b. Launching When Dispenser is Inoperable or Unavailable.

(1) Attach static line XM164 to cargo tie-down near door.

(2) Attach free end of static line to flare pull cable assembly (fig. 2-16).

(3) Remove safety pin from fuze and retain for reinsertion if flare is not launched.

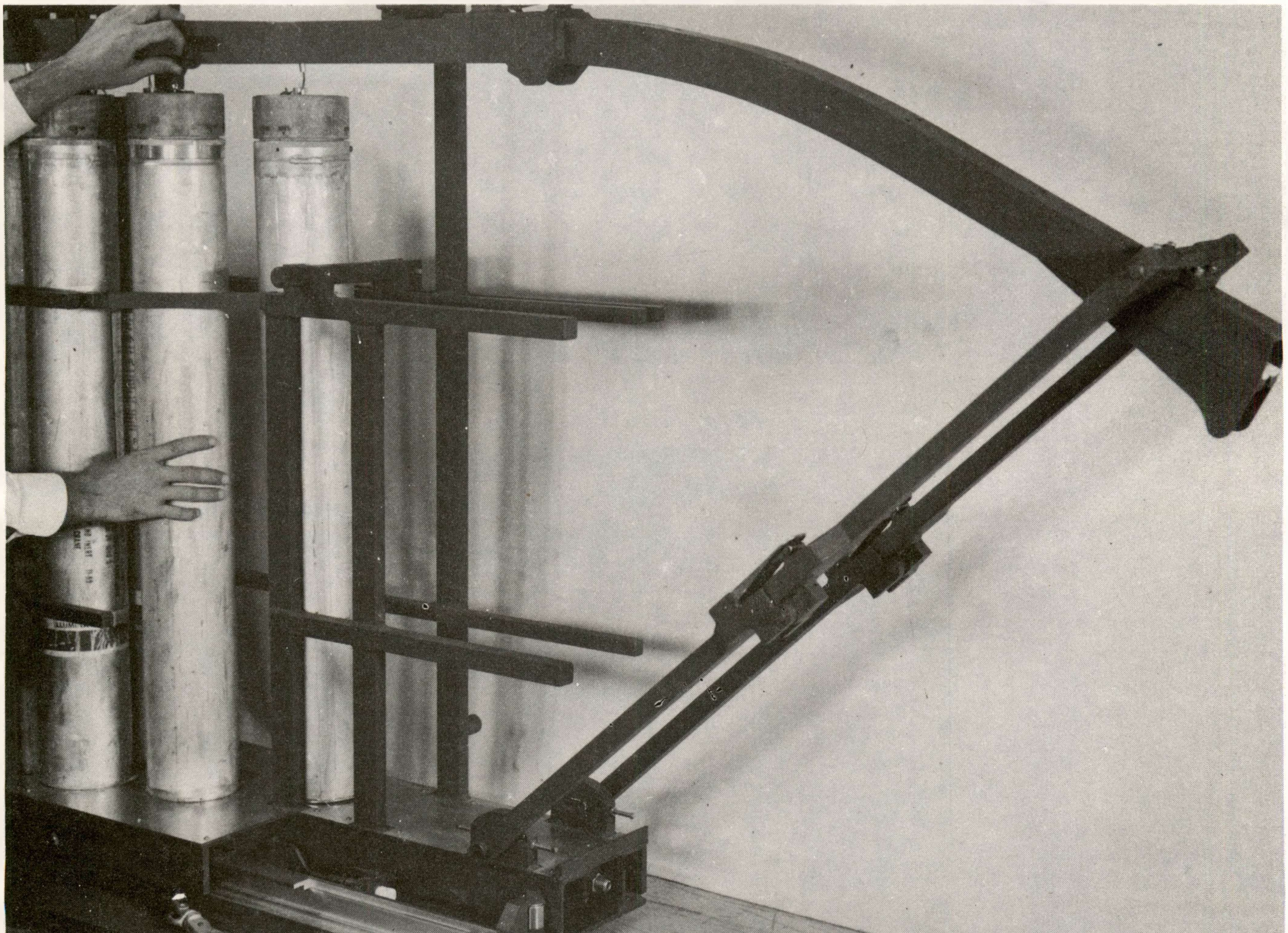

Figure 2-14. Disengaging pull cable assembly from dispenser assembly.

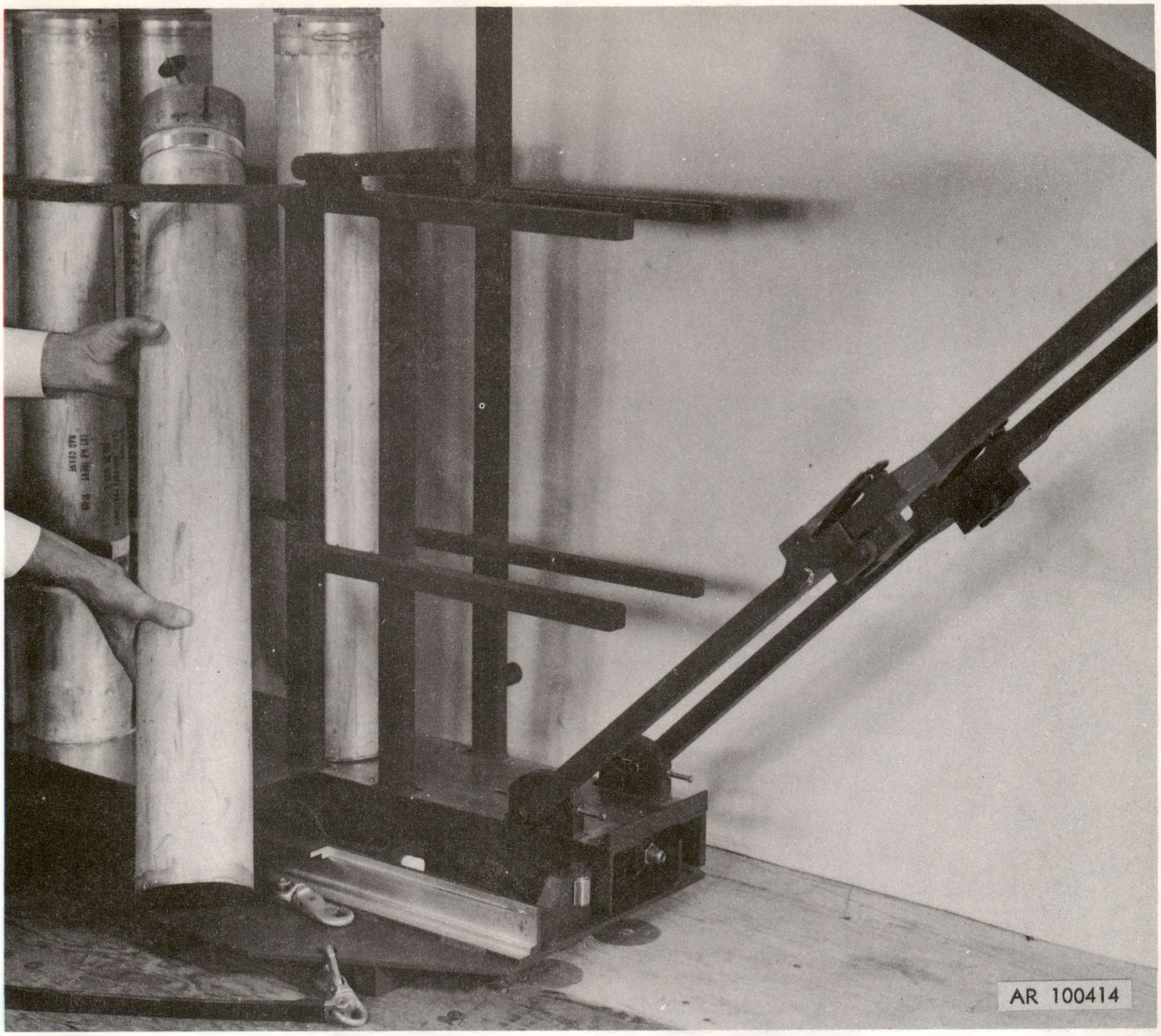

Figure 2-15. Removing flare from dispenser assembly.

(4) Throw flare from helicopter (fig. 2-17), base end first, assuring that flare clears helicopter.

WARNING

If flare does not separate from static line XM164, do *not* attempt to pull flare back into helicopter. Detach static line XM164 from tiedown ring and let static line and flare fall away.

(5) After flare has fallen away from aircraft, retrieve static line and retain pull cable assembly for disposal after landing. Stow static line XM164 in helicopter as soon as last flare is launched.

c. Jettisoning Dispenser Assembly With Flares Due to Emergency in Flight.

NOTE

During flight, bail must be out from under handle of firing device, and safety valve handle must be in ARM position.

To jettison dispenser assembly, pilot must lift safety switch cover on firing panel, place safety switch in ARM position, and press firing device handle. The dispenser assembly, with flares, is automatically ejected from helicopter.

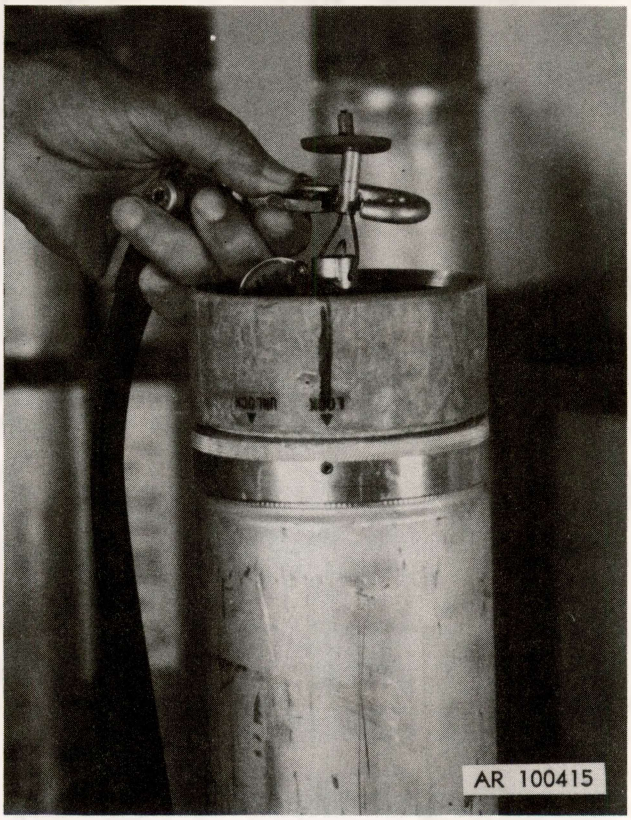

Figure 2-16. Attaching static line XM164 to pull cable assembly.

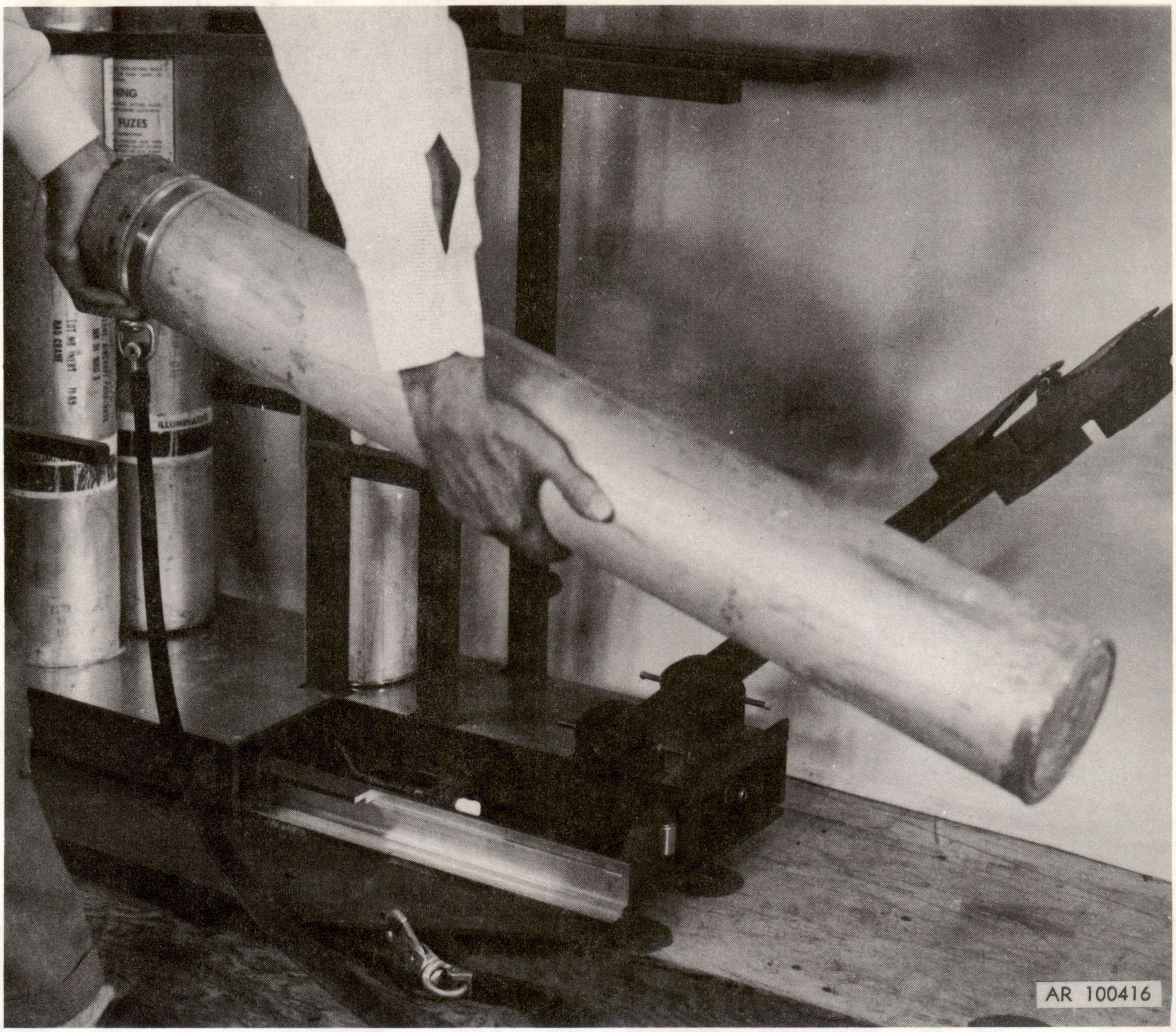

Figure 2–17. Launching flare by hand.

Section III. REMOVAL OF FLARE DISPENSER XM19 FROM HELICOPTER

2–7. Removal of Dispenser

WARNING

Prior to attempting any removal procedures, assure that safety valve handle is in SAFE position, that bail is under handle of firing device, and that safety switch is in SAFE position with cover down.

a. Assure that safety valve handle is in SAFE position, that bail is under handle of firing device, and that safety switch is in SAFE position with cover down.

b. Detach cable from firing panel and nitrogen cylinder.

c. Unlock snap-screws holding firing panel to instrument panel. Remove firing panel.

d. Retract snout.

e. Loosen locking nut and turn vibration snubber screw counterclockwise to fully extended position.

f. Manually move interlock handle away from rail to disengage interlocks from dispenser assembly.

g. Roll dispenser assembly off track plate.

h. Remove hexagon nuts from snap-on fittings.

i. Remove track plate from helicopter floor.

j. Remove snap-on fittings.

2-8. Removal of Jettison Assembly If Dispenser Assembly Has Been Jettisoned

If dispenser assembly has been jettisoned, perform steps *b*, *c*, *e*, *h*, i, and j of paragraph 2-7.

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CHAPTER 3

ORGANIZATIONAL MAINTENANCE

Section I. SERVICE UPON RECEIPT OF MATERIAL

3-1. Shipping Container for Flare

NOTE

The shipping container is nonhydroscopic unless pierced, cracked, or badly dented. Moisture on exterior surfaces does not indicate moisture contamination of flare.

a. Inspect container for damage as follows:

(1) Cracked container.

(2) Tape missing or torn.

(3) Pieces of container missing, exposing flare.

(4) Badly dented container.

b. If a condition listed in *a* above is observed, unpack and inspect flares (para 3-2).

3-2. Flares

a. Open container by cutting tape along seam, taking care not to damage container.

b. Lift off top.

c. Remove flares from container.

d. If barrier bag is torn or pierced, or if shipping container is badly dented so as to cause possible damage to flare, open barrier bag and inspect flare (*e* below).

e. If flare shows evidence of moisture, dents, or bulges that could render the flare inoperable, contact authorized disposal personnel for disposition.

f. Repackage serviceable flares, using salvaged packing materials. Touch up markings as needed. Give repackaged flares priority of issue.

3-3. Shipping Crate for Dispenser

Inspect shipping crate. Open damaged crate, if it appears that contents could be unserviceable. Inspect dispenser (para 3-4).

3-4. Flare Dispenser XM19

a. Dispenser Assembly.

(1) Inspect dispenser assembly for damage that renders it unserviceable.

(2) If dispenser assembly is serviceable, set aside for repacking.

(3) If dispenser assembly is unserviceable, set aside for disposition.

b. Jettison Assembly.

(1) Inspect track plate for damage that renders it unserviceable, such as broken seal on nitrogen cylinder, bent rails, etc.

(*a*) If track plate is serviceable, set aside for repacking.

(b) If track plate is unserviceable, set aside for disposition after removing any serviceable nitrogen cylinder (with attached parts) for possible future use.

(2) Inspect firing panel, cable, and test set for visible damage.

(*a*) If there is no visible damage, set items aside for repacking.

(*b*) If there is visible damage, perform electrical continuity test in accordance with paragraph 2-3*b*.

1. If electrical continuity test reveals no defective items, set items aside for repacking.

2. If electrical continuity test reveals defective items, set items aside for disposition.

Section II. ORGANIZATIONAL MAINTENANCE

3-5. Flares

Except for touchup of markings (para 3-6), the only maintenance to be performed on flares is contained in paragraph 3-1 and 3-2.

3-6. Touchup Markings on Flares

Flares bear the information shown below. Those markings indicated by asterisk are essential. If any of the essential markings are missing, notify authorized disposal personnel.

a. Nomenclature and model designation.*

b. Federal Stock Number.

c. Lot number.*

d. DODIC number.

e. Loading date.*

f. Manufacturer's name or symbol.

g. Loading facility.

h. The words FORWARD OR UP and DOWN OR AFT indicate the forward and aft positions on the flare.*

i. Fuze setting and safing instructions on label on the case.*

j. A brown and white band around the lower end of the flare with the word ILLUMINATING printed on it twice.

k. The words THIS END DOWN OR AFT WHEN LAUNCHED located on the flare end cap.*

3-7. Touchup Markings on Flare Containers and Dispenser Crates

a. The following information must be legible on each container:

(1) Nomenclature.

(2) Federal stock number (including DODIC).

(3) Lot number.

(4) Date of manufacture.

(5) Quantity.

b. If even *part* of the original markings are obliterated, apply new markings adjacent to original markings, using a waterproof ink marker or a chinamarker pencil.

CHAPTER 4

SHIPMENT AND STORAGE

Section I. SHIPMENT

4-1. Flares

a. Precautions.

(1) Handle flares carefully. Improper handling can degrade item so that it will not accomplish its mission.

(2) Assure that flares being transported will not be damaged, contaminated, or otherwise degraded so that they become dangerous or their usefulness impaired.

(3) Do not roll, drop, or subject flares to high-shock loads.

(4) Return as unserviceable flares subjected to severe handling that are damaged or suspected of being damaged.

b. Instructions.

(1) In transporting flares, block and brace adequately to withstand sudden stops, starts, and off-road operations.

(2) Load flares in attitude which prevents rolling.

(3) If packing is broken or damaged, and flares still serviceable, restore or replace packing by using packing material from expended ammunition. Assure that all markings (i.e., lot identification, nomenclature, FSN, etc.) are transferred to reworked packing.

c. Palletizing for Retrograde Shipment.

(1) This instruction is applicable if the flares do not have a vent hole. An end cap may be propelled from an unvented flare due to generation of hydrogen gas.

(2) In order to prevent an end cap from leaving the area of the pallet, block its path with plywood. Obtain two pieces of plywood for each pallet, 85-1/2 inches long, 26 inches wide, and 3/4 inch thick. Position one piece of plywood over one end of the stack of flare containers and place the other piece of plywood over the opposite end of the stack of flare containers. Fasten the plywood to the stack with two steel bands. Pass each band under the pallet, up the sides of the plywood, and across the top of the stack.

d. Data.

Department of Transportation (DOT or ICC shipping designation)	Special fireworks
DOT shipping class	A
Federal Stock Number (FSN) and Department of Defense Identification Code (DODIC):	
Mk 45 Mod 0	1370-088-5658 (L473)
Mk 45 Mod 0 with adapter	1370-461-1526 (L424)
Gross weight (including 2 flares)	60 lb
Cubical displacement of shipping container	1.89 cu ft
Descriptive nomenclature of packed item (L473)	Flare, Aircraft: Parachute, White, Mk 45 Mod 0
(L424)	Flare, Aircraft: Parachute, Mk 45 Mod 0 with Adapter for Dispenser XM19

4-2. Flare Dispenser XM19—Data

Department of Transportation (DOT) shipping designation	Bomb Rack, Airplane
DOT shipping class	N/A
Federal Stock Number (FSN) and Department of Defense Identification Code (DODIC)	1370-179-6011 (L106)
Gross weight	362.0 lb
Cubical displacement of shipping containers	57.3 cu ft
Descriptive nomenclature of packed items	Dispenser, Flare: XM19

Section II. STORAGE

4-3. Flares

a. Precautions.

(1) Flares may be adversely affected by moisture and extremes in temperature. Consequently, they should be stored in dry, well ventilated places.

(2) When it is necessary to store flares in the open, select storage site free of power lines and electric cables.

(3) Do not locate flares adjacent to reservoirs, water mains, or sewer lines.

(4) Select level, well drained sites free of readily ignitable and flammable materials.

(5) Do not store under trees or adjacent to towers or other structures which attract lightning.

(6) Provide nonflammable or fire-resistant overhead covers (such as tarpaulin) for all flares. Maintain overhead air space of approximately 18 inches between cover and flares. Keep cover at least 6 inches from pile on ends and at sides, to permit circulation of air.

b. Data.

Quantity-distance class	2
Storage compatibility group	N
Storage temperature limits:	
Lower limit	−65° F. for not more than 3 days
	+160° F. for not more than 4 hours per day

NOTE

In unventilated containers, inclosures, shelters, freight cars, closed vehicles, and similar structures, temperatures considerably higher than those outside may be encountered. Temperatures of approximately +160° F. may be developed within such structures exposed to an outside air temperature of +125° F. plus the full impact of solar radiation for a period of 4 hours.

c. Quantity-Distance Requirements. Quantity-distance requirements are shown in table 4-1.

Table 4-1. Quantity-Distance Requirements

Quantity		Unbarricaded distance (feet)		
Pounds (over)	Pounds (not over)	Inhabited building distance	Public highway & public railway distances	Magazine and intraline distance
100	1,000	75	75	50
1,000	5,000	115	115	75
5,000	10,000	150	150	100
10,000	20,000	190	190	125
20,000	30,000	215	215	145

NOTE

In addition to the distance established in the table, maintain a distance of 400 feet between stored flares and flammable fuels, and a minimum distance of 800 feet between stored flares and massed (stored) vehicles.

4-4. Flare Dispenser XM19—Data

Quantity distance class	1
Storage compatibility group	BEN

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APPENDIX A

REFERENCES

A-1. Publication Indexes

The following publication indexes should be consulted frequently for the latest changes or revisions of references given in this appendix and for new publications relating to the material covered in this manual.

Index of Administrative Publications	DA Pam 310-1
Index of Blank Forms	DA Pam 310-2
Index of Doctrinal, Training, and Organizational Publications	DA Pam 310-3
Index of Technical Manuals, Technical Bulletins, Supply Manuals (types 7, 8, and 9), Supply Bulletins, and Lubrication Orders.	DA Pam 310-4
Index of Supply Catalogs and Supply Manuals (excluding types 7, 8, and 9).	DA Pam 310-6

A-2. Technical Manuals

Ammunition and Explosives Standards	TM 9-1300-206
Destruction of Conventional Ammunition and Improved Conventional Munitions to Prevent Enemy Use (Excluding Toxic and Incapacitating Chemical Agents for Combat Unit).	TM 750-244-5-1
The Army Maintenance Management System (TAMMS)	TM 38-750

A-3. Army Regulations

Accident Reporting and Records	AR 385-40
Malfunctions Involving Ammunition and Explosives	AR 75-1
Regulations for Firing Ammunition for Training, Target Practice, and Combat.	AR 385-63
Report of Packaging and Handling Deficiencies	AR 700-58
Reporting of Transportation Discrepancies in Shipments	AR 55-38

A-4. Forms

Accident Report	DA Form 285
Ammunition Condition Report	DA Form 2415
Discrepancy in Shipment Report	SF 361
Recommended Changes to Publications and Blank Forms	DA Form 2028
Report of Packaging and Handling Deficiencies	DD Form 6

APPENDIX B

EXPENDABLE ITEMS

Section I. INTRODUCTION

B-1. Scope

This appendix lists items which are required for organizational maintenance.

B-2. Explanation of Columns

a. Federal Stock Numbers, Column 1. Indicates the Federal stock number assigned to the item and will be used for requisitioning purposes.

b. Description, Column 2. Indicates the item name and brief description.

c. Military Specification, Column 3. Indicates military specification assigned to the item.

d. Unit of Issue. Indicates the unit of issue of each item.

Section II. EXPENDABLE SUPPLIES

(1) Federal stock No.	(2) Description	(3) Military specification	(4) Unit of issue
8135-269-8090	TAPE, PRESSURE SENSITIVE ADHESIVE: 2 in. wide	PPP-T-60	roll (60 yds)
1370-962-1798	STATIC LINE, DROP, FLARE: XM164	—	each
7510-240-1526	PENCIL: china marking	SS-P-196	dozen (12 pencils)

NOTE

Expendable supplies should be requisitioned through normal supply channels to comply with maintenance requirements.

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APPENDIX C

MAINTENANCE ALLOCATION CHART

Section I. INTRODUCTION

C-1. General

a. The Maintenance Allocation Chart designates responsibility for the performance of maintenance functions.

b. Only the lowest level of maintenance authorized to perform a maintenance function is indicated.

c. A maintenance function assigned a maintenance level will automatically be authorized to be performed at any higher maintenance level.

d. A maintenance function that cannot be performed at the assigned level of maintenance for any reason may be evacuated to the next higher maintenance organization. Higher maintenance levels will perform the maintenance functions of lower maintenance levels when required or directed by the appropriate commander.

C-2. Definitions of Maintenance Functions

The implementation of maintenance tasks will be consistent with the assigned maintenance in accordance with the following definitions.

a. Inspect. To determine the serviceability of an item by comparing its physical, mechanical, and/or electrical characteristics with established standards through examination.

b. Test. To verify serviceability and to detect incipient failure by measuring the mechanical or electrical characteristics of an item and comparing those characteristics with prescribed standards.

c. Service. Operations required periodically to keep an item in proper operating condition.

(1) *Unpack.* To remove item from packing box for service or when required for the performance of other maintenance operations.

(2) *Repack.* To return item to packing box after service and other maintenance operations.

(3) *Clean.* TO rid the item of contamination.

(4) *Touch up.* To spot paint scratched or blistered surfaces.

(5) *Mark.* To restore obliterated identification.

d. Install. To emplace, seat, or fix into position an item in a manner to allow the proper functioning of the equipment.

e. Adjust. To maintain within prescribed limits by bringing into proper or exact position, or by setting the operating characteristics to the specified parameters.

f. Renovate. To restore item to serviceable condition.

(1) *Paint.* To repaint the entire item.

(2) *Repair.* To restore serviceability to an item by correcting specific damage, fault, malfunction, or failure through the application of maintenance services or other maintenance actions.

(3) *Replace.* To substitute a serviceable component in a manner to allow the proper functioning of equipment.

C-3. Explanation of Format

a. Column 1, Group Number. Column 1 lists group numbers, the purpose of which is to identify components, assemblies, and subassemblies with the next higher assembly.

b. Column 2, Functional Group. Column 2 lists the next higher assembly group and the item names of components, assemblies, and subassemblies within the group for which maintenance is authorized.

c. Column 3, Maintenance Function. Column 3 lists the 12 maintenance functions defined in paragraph C-2 above. Each maintenance function required for an item is specified by the sym-

bol among those listed in *d* below which indicates the level responsible for the required maintenance.

d. Use of Symbols. The following symbols are used to prescribe work function responsibility:

C—Operator/Crew.
O—Organization.
F—Direct Support.
H—General Support.
D—Depot.

e. Column 4, Tools and Equipment. This column specifies, by code, those tools and test equipment required to perform the designated function.

f. Column 5, Remarks. Self-explanatory.

Section II. MAINTENANCE ALLOCATION CHART FOR FLARE, AIRCRAFT: PARACHUTE, WHITE, MK 45 MOD 0; FLARE, AIRCRAFT: PARACHUTE, MK 45 MOD 0 WITH ADAPTER FOR DISPENSER XM19; DISPENSER, FLARE: XM19; AND STATIC LINE, DROP, FLARE: XM164

(1)	(2)	(3)												(4)	(5)
		Maintenance function													
				Service							Renovate				
Group No.	Functional group	Inspect	Test	Unpack	Repack	Clean	Touch up	Mark	Install	Adjust	Paint	Repair	Replace	Tools and equipment	Remarks
	01 GROUP—FLARES														
0101	Flare, Aircraft: Parachute, White, Mk 45 Mod 0	O		O	O	O	O		O	O					
0102	Flare, Aircraft: Parachute Mk 45, Mod 0, with Adapter for Dispenser XM19	O		O	O	O	O		O	O					
0103	Packing Material	O				O	O						O		
	02 GROUP—DISPENSER, FLARE: XM19														
0201	Dispenser Assembly	O		O	O	O	O		O	O					
0202	Loading Gate	O				O									
0203	Dispensing Gate	O				O									
0204	Tension Latches	O								O					
0205	Rollers	O				O									
0206	Jettison Assembly	O	O	O	O	O	O		O	O					
0207	Track Plate	O				O			O	O					
0208	Nitrogen Cylinder	O							O				O		
0209	Safety Valve	O													
0210	Interlocks	O	O			O									
0211	Piston	O													
0212	Piston Tube	O													
0213	Firing Panel	O	O	O	O				O				O		
0214	Cable	O	O	O	O				O				O		
0215	Test set for XM19	O							O				O		
	03 GROUP—STATIC LINE, DROP, FLARE: XM164														
0301	Static Line, Drop, Flare: XM164	O							O						

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APPENDIX D

ORGANIZATIONAL MAINTENANCE REPAIR PARTS AND SPECIAL TOOLS LIST

Section I. INTRODUCTION

D-1. Scope

This appendix lists repair parts that are required for the performance of organizational maintenance on flares and dispensers.

D-2. Explanation of Columns

The following provides an explanation of columns found in section II:

a. Illustration. This column is divided as follows:

(1) *Figure number.* Indicates the figure number of the illustration in which the item is shown.

(2) *Item number.* Indicates the number used to identify each item called out in the illustration.

b. Source, Maintenance, and Recoverability Codes (SMR).

(1) *Source code.* Source codes are assigned to support items to indicate the manner of acquiring support items for maintenance, repair, or overhaul of end items. Source code is entered in the first and second positions of the SMR code as follows:

Code	*Explanation*
XB	Item not stocked and the indicated maintenance category requiring such items will attempt to obtain these through cannibalization or salvage. If the item is not available through cannibalization, it may be requisitioned from the next higher maintenance level.

(2) *Maintenance code.* Maintenance code consists of two parts—USE code (third position) and REPAIR code (fourth position). USE indicates the lowest maintenance level authorized to remove, replace, and use the listed item. REPAIR code indicates whether the item is to be repaired, and identifies the lowest maintenance level authorized to repair the listed item. Maintenance codes are:

Code	*Explanation*
Use	
O	Support item is removed, replaced, used at the organizational level.
Repair	
Z	Nonreparable. No repair is authorized.

(3) *Recoverability code.* Recoverability code (fifth position) indicates the disposition action on an unserviceable item. Recoverability code is:

Code	*Explanation*
Z	Nonreparable item. When unserviceable, condemn and dispose at the level indicated in position 3.

c. Federal Stock Number. Indicates the Federal stock number assigned to the item.

d. Part Number. Indicates the primary number used by the manufacturer (individual, company, firm, corporation, or Government activity), which controls the design and characteristics of the item by means of its engineering drawings, specifications standards, and inspection requirements, to identify an item or range of items.

e. Federal Supply Code for Manufacturer (FSCM). The FSCM is a 5-digit numeric code listed in SB 708-42 which is used to identify the manufacturer, distributor, or Government agency, etc.

f. Description. Indicates the Federal item name and, if required, a minimum description to identify the item.

g. Unit of Measure (U/M). Indicates the standard of the basic quantity of the listed item as used in performing the actual maintenance function.

h. Quantity Incorporated in Unit. Indicates the quantity of the item used with or on the equipment.

Section II. REPAIR PARTS LIST

(1) Illustration (a) Fig. No.	(1) Illustration (b) Item No.	(2) SMR code	(3) Federal stock No.	(4) Part No.	(5) Fed supply code for mfr	(6) Description	(7) Unit of meas	(8) Qty inc in unit
						GROUP 01—FLARES		
						0103—PACKING MATERIAL		
1–10		XBOZZ		Nav Aer Dwg No. 2816268		Container, Top*	ea	1
1–10		XBOZZ		Nav Aer Dwg No. 2816269		Container, Bottom*	ea	1
						GROUP 02—DISPENSER, FLARE: XM19		
						0208—NITROGEN CYLINDER		
1–7				9247440		Nitrogen Cylinder**	ea	1
						0213—FIRING PANEL		
1–8		XBOZZ		9249360		Firing Panel	ea	1
						0214—CABLE		
1–8		XBOZZ		9251397		Cable	ea	1
						0215—TEST SET FOR XM19		
2–8		XBOZZ		9255382		Test set for XM19	ea	1

*One each of these parts is required for packaging two flares.

**Available by sending an expended nitrogen cylinder to Picatinny Arsenal, Dover, NJ, ATTN: SMUPA-AD-M-A. Not available from field stock.

By Order of the Secretary of the Army:

CREIGHTON W. ABRAMS
General, United States Army
Chief of Staff

Official:
VERNE L. BOWERS
Major General, United States Army
The Adjutant General

Distribution:
To be distributed in accordance with DA Form 12-40, (qty rqr block No. 320) Operator maintenance requirements for Pyrotechnics.

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CHAPTER 5

SHIPMENT AND STORAGE

Section I. SHIPMENT

5–1. Precautions

a. Handle flares carefully. Improper handling can degrade item so that it will not accomplish its mission.

b. Assure that flares being transported will not be damaged, contaminated or otherwise degraded so that they become dangerous or their usefulness impaired.

c. Do not roll, drop or subject flares to high-shock loads.

d. Return as unserviceable flares subjected to severe handling that are damaged or suspected of being damaged.

5–2. Instructions

a. Block and brace flares transported in trucks, jeeps and other tactical vehicles. Block and brace adequately to withstand sudden stops and starts, and off-road operations.

b. Load flares in attitude which prevents rolling.

c. If packing is broken or damaged, and flares are still serviceable, restore or replace packing by using packing material from expended ammunition. Assure that all markings (i.e., lot identification, nomenclature, FSN, etc.) are transferred to reworked packing.

5–3. Data

Department of Transportation (DOT or ICC shipping designation)	Special fireworks
DOT shipping class	A
Federal Stock Number (FSN) and Department of Defense Identification Code (DODIC)	1370–088–5658 (L473) 1370–783–5180 (L416)
Gross weight	52.0 lb
Cubical displacement of shipping container	1.89 cu ft
Descriptive nomenclature of packed item	Flare, Aircraft: Parachute, Mk45

Section II. STORAGE

5–4. Precautions

Flares and other pyrotechnic devices may be adversely affected by moisture and extremes in temperature. Consequently, they should be stored in dry, well ventilated places.

a. When it is necessary to store flares in the open, select storage site free of power lines and electric cables.

b. Do not locate flares adjacent to reservoirs, water mains or sewer lines.

c. Select level, well drained sites free of readily ignitable and flammable materials.

d. Do not store under trees or adjacent to towers or other structures which attract lightning.

5–5. Data

a. Data covering storage of flares appear below:

Quantity-distance class	2
Storage compatibility group	N
Storage temperature limits:	
Lower limit	–65°F. for not more than 3 days
Upper limit	+160°F. for not more than 4 hours per day

NOTE

In unventilated containers, inclosures, shelters, freight cars, closed vehicles, and similar structures, temperatures considerably higher than those outside may be encountered. Temperatures of approximately +160°F. may be developed within such structures exposed to an outside air temperature of +125°F. plus the full impact of solar radiation for a period of four hours.

Table 5-1. Quantity Distance Requirements

Quantity		Unbarricaded distance (feet)		
Pounds (over)	Pounds (not over)	Inhabited building distance	Public highway & public railway distances	Magazine and intraline distance
100	1,000	75	75	50
1,000	5,000	115	115	75
5,000	10,000	150	150	100
10,000	20,000	190	190	125
20,000	30,000	215	215	145

5-6. Procedures

a. Use heavy, well supported dunnage, fabricated locally from logs, ammunition boxes, etc., to keep bottom tier off ground.

b. Allow at least 6-inch space beneath pile for air circulation.

c. Dig suitable trenches to prevent water from flowing under pile. Arrange containers so that air can circulate through stack.

d. Use hardstand of bituminous material or gravel and sand in preference to excessive dunnage.

e. Cover stacks with nonflammable or fire-resistant materials (e.g., tarpaulin). Maintain overhead air space of approximately 18 inches between cover and flares. Raise cover at least 6 inches from pile on ends and sides to permit circulation of air.

APPENDIX A

REFERENCES

Safeguarding Defense Information	AR 380-5
Fire Report	AR 385-12
Accident Reporting and Records	AR 385-40
Regulations for Firing Ammunition for Training, Target Practice, and Combat	AR 385-63
Malfunctions Involving Ammunition and Explosives	AR 700-1300-8
Fire Report	DA Form 5-2
Accident Report	DA Form 285
Record of Injury	DA Form 1051
Record of Comments on Publications	DA Form 1598
Index of Technical Manuals, Technical Bulletins, Supply Manuals (types 7, 8 and 9), Supply Bulletins, and Lubrication Orders	DA Pam 310-4
Care, Handling, Preservation and Destruction of Ammunition	TM 9-1300-206
Military Pyrotechnics	TM 9-1370-200
Army Equipment Record Procedures	TM 38-750

APPENDIX B

BASIC ISSUE ITEMS LIST

SWR code	Federal stock number	Description Reference No. & Mfr. code	Usable on code	Unit of meas	Qty inc in unit
		The following items are used with Flare Mk45:			
GSA (75)	8135-269-8090	Tape, Pressure Sensitive Adhesive, PPP-T-60, 81348		ro	60 yds
BA	1370-962-1798	XM164 Static Line, Flare, 10535856, 19200		ea	1
GSA (75)	7510-240-1526	Pencil, China-Marking, SS-P-196, 81348		pkg	6

1708/1710

By Order of the Secretary of the Army:

W. C. WESTMORELAND,
General, United States Army,
Chief of Staff.

Official:

KENNETH G. WICKHAM
Major General, United States Army,
The Adjutant General.

Distribution:

Active Army:

USASA (2)
DCSLOG (2)
CNGB (1)
CofEngrs (4)
UAMB (2)
USACDC (2)
USACDC Agcy (2)
USAMC (12)
USAWECOM (2)
USAMUCOM (10)
USAMICOM (10)
USATECOM (2)
USAECOM (2)
USATACOM (2)
USCONARC (3)
ARADCOM (2)
ARADCOM Rgn (2)
OS Maj Comd (2) except
  USAREUR (5)
LOGCOMD (2) except
  1st LOGCOMD (4)
  2nd LOGCOMD (4)
MDW (1)
Armies (3) except
  1st USA (5)
Corps (2)
Div (2)
Instl (2)
Svc Colleges (2)
Br Svc Sch (12) except
  USAOC&S (20)
  UACMLCS (10)
  USA FA Sch (10)
  USAARMS (10)
PMS Sr Div Ord Units (1)
Army Dep (2) except
  SVAD (50)
  LEAD (4)
Gen Dep (5)
Ord Sec, Gen Dep (5)
Ord Dep (5)
Arsenals (4) except
  Edgewood (10)
  Picatinny (75)
Proc Dist (3)
PG (2)
POE (2)
Mil Msn (2)
MAAG (2)

MTMTS (2)
EAMTMTS (2)
WAMTMTS (2)
JBUSMC (2)
JUSMAGG (2)
USAAPSA (10)
Log Con Ofc (2)
Fld Comd, DASA (1)
Units org under fol TOE:—2 copies ea
  1-7
  1-47
  1-55
  1-56
  1-57
  1-58
  1-75
  1-76
  1-77
  1-78
  1-87
  1-127
  1-137
  1-207
  1-252
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  9-7
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  9-47
  9-76
  9-86
  9-87
  9-367
  9-500
  29-55
  29-56
  29-57
  29-109
  31-105
  31-106
  31-107

ARNG: State AG (3); units—same as Active Army except allowance is one (1) copy each.

USAR: None.

For explanation of abbreviations used, see AR 320-50.

☆ U. S. GOVERNMENT PRINTING OFFICE: 1969—390993/89